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# Road Traffic in Winter

Summary of publications in the research programme



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Road Administration**  
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## ABSTRACT

The purpose of the ROAD TRAFFIC IN WINTER- research programme was to search for the social optimum between studded tyre usage and winter maintenance. The programme consisted of over forty separate researches concentrating on:

- Traffic safety
- Environmental effects
- Maintenance
- Vehicular costs
- Road user experiences

The total costs of nine alternatives according to different salting policies and stud usages were calculated using the following array:

### ROAD TRAFFIC IN WINTER-SCENARIOS

#### CHANGE IN TOTAL COSTS COMPARED TO THE BASIC SITUATION

Change in costs Million US\$/a	Salting 120 000 t/a	Light salting c. 60 000 t/a	Nearly unsalted > 30 000 t/a
< 95% of pass. cars with studs	Basic situation	36	36
c. 50% of pass. cars with studs	47	91	98
> 20% of pass. cars with studs	100	160	202

1 US\$=4,5 FIM

It seems that the basic situation (when the research programme began) is economically better than any other of the studied alternatives. But if we look at the results from the point of view of the Finnish National Road Administration (Finnra), environment or driver, it is not so apparent.

From the perspective of the Finnra, reducing the use of studded tyres and the amount of salt from the basic situation by a half, would be the most favourable. The decrease in stud and salt use would be beneficial also for the environment, but the no salt and studless alternative would not, however, be the most economical. For the driver roads without salt and tyres without studs offer the most favourable alternative.

When searching for the social optimum the most important factor is accident costs, which in the studless and unsalted alternative are extremely high. The accident costs weigh the result towards the existing alternative i.e. the use of salting and studded tyres should be continued despite of the disadvantages. Studded tyres give added safety especially to insecure drivers in varying road conditions. Salting also evens the variations in the circumstances and allows safe and fluent traffic in the winter.



## **TRAFFIC SAFETY**

### **Tyre research studies**

- The condition of the tyres does not affect the speeds in winter time. The drivers who thought their tyres were inferior did not drive slower than others.
- The drivers' knowledge about the condition of their tyres was poor and their knowledge about the condition of their studs was even worse.
- The grip of the new light studs is quite similar to that of the older steel studs, but the wear of pavements is only about a half. The serviceable life of the light studs varies considerably between different makes.
- Studded tyres as a whole are better than studless winter tyres, so called friction tyres. A car equipped with ABS brakes and friction tyres is a good combination if driving under icy conditions can be avoided. The differences between studs are huge.

### **Driver behaviour**

- The change to friction tyres did not affect the amount or time of driving. Drivers with friction tyres drove slower than those with studded tyres in built-up areas and at sharp curves. They also maintained a longer safety margin to the car in front. The changes were not, however, sufficient to keep the risk at the same level as with the drivers with studded tyres. Otherwise the change to studless winter tyres did not affect driving speeds in adverse road conditions.
- In good road conditions the increase in speed of the friction tyre users can have a negative effect on traffic safety.
- As age and driving experience increase the risk of less accidents decreases, but particularly the risk of severe accidents is at its greatest for young and old drivers.
- Drivers are not aware of the road conditions. The road conditions are usually evaluated as less slippery than they really are. On the other hand the condition of the tyres is overestimated. Under slippery conditions, more than half of the drivers (56%) estimated the conditions non-slippery or semi-slippery. Very slippery road conditions were deemed by 13% as non-slippery and only by half of the drivers as slippery or quite slippery.
- Although the road conditions are considered as slippery, people do not slow down sufficiently and the risk increases. In snowy conditions speeds decrease by 4-5 kmph and in slippery conditions by 3-7 kmph.
- Drivers seem to take the winter speed limits as a "recommended speed" regardless of how slippery the road surface is.
- Drivers in queues do not keep adequate safety margins. This is a problem especially in the capital region. In winter conditions one in every four keep too small safety margins (under 1.5 sec).
- Studded tyres of good condition increase safety. When studying accidents resulting in loss of life, 30% of the tyres were classified as being of bad condition (in normal traffic the percentage is 3%).

## Reduced salting experiments

- During the reduced salting experiments in Kuopio (situated in the middle of Finland) the amount of sanding tripled. As small amounts of salt are used in the sand to enhance adhesion, the total amount of salt was reduced by 80%.
- On the experimental roads, friction levels below 0.3 were twice as common as on control roads. Less than 3% of the time the friction levels were below 0.2 with no difference between experimental and control roads.
- During the first winter there were 27 accidents leading to injuries or death on the test roads and 25 during the second winter. These numbers correspond to the mean of the last five years (26.8). Taking into account the fact that accidents decreased simultaneously on the comparison roads, the experiment has increased the personal injury accidents by 5 %. On the roads in maintenance class I, comprising over 80 % of the test roads, the personal injury accidents increased by about 20 %.

## ENVIRONMENTAL EFFECTS

### Ground water

- The salt pollution of the ground water is a problem in southern Finland, where the most heavily trafficked roads are built on an esker. Roads built on top and following an esker are adverse.
- In general, salt pollution develops slower in larger aquifers. When the esker material is coarser the groundwater flow velocity increases => water circulation increases => salt pollution is slower.
- Dense layers situated unfavourably can direct the salt pollution of groundwater.
- At the coastal areas excessive intake of water can result in salty seawater pushing into the place of fresh water. In the old sea water reserves of the coastal areas the salt concentration can be high.
- According to the modelling studies, the salt amount of 5 t/km/a which corresponds well to the current usage does not usually raise the salt concentration in groundwater. In some cases the salt concentration can even decrease a bit.
- Salt deposits at the bottom of aquifers has been dreaded. This didn't happen in the modelling studies. The sinking of salty water would seem possible only with extreme salt concentrations or very small flow velocities. Continued salting with great amounts of salt (10-20 t/km/a) will eventually lead to excessive increase of the salt concentration at small aquifers.
- The environmental risks of salting can be controlled by protection of the most risky areas and keeping the salt amount as small as technically possible.



## **Vegetation**

- The study indicated that even modest use of road salt in the road region of Savo-Karjala resulted in accumulation of salt in the pine needles. However, the salt concentrations were not high enough to cause any visible injuries. According to the study the reduced use of road salt has proved to be good for the roadside vegetation.

## **Dust**

- Dust can cause breathing symptoms to people with allergies. The quartz dust from the road and sanding materials can be hazardous to health but the amounts of quartz dust remain so small that they can not form a risk factor according to the current knowledge.
- Dusting and formation of wet, dirty fog can be controlled by traditional maintenance i.e. by opening up slush drains, moving snowbanks, well-timed peeling of ice from the embankments and by auxiliary measures (draining melt water, washing and brushing) as the need arises. Constructional road improvements can also be used to decrease dusting and/or assist in the maintenance needed to decrease dust and dusting.

## **Alternatives to road salt**

- CMA (calciummagnesiumacetate) is in general similar to NaCl (sodium chloride) in anti-icing: Both can be applied using the same equipment and for similar circumstances. The dosage of CMA has to be 1.3 times the weight of NaCl. As the volume weight of CMA is about 63% from that of NaCl, one load on CMA is sufficient for about half the road length of NaCl. The effect of CMA decreases significantly at temperatures below  $-5^{\circ}\text{C}$ . CMA melts slower than NaCl and it is not effective enough for packed snow or ice.
- In Finland the oxygen content in aquifers is quite low. That's why CMA is not so suitable for us. CMA causes much less corrosion than NaCl.

## **WINTER MAINTENANCE**

- In the studies of the logistic effects of winter maintenance the number and recurrence of late arrivals was considered more important than the time of lateness of a single transport.
- Reducing the amount of salt increased the transport hours by 1-5% and studless winter tyres by 2%. Using less salt increases the annual transport costs by 0.05-0.5% and using studless winter tyres by 0.1-0.3%.

- Using less salt increases the standard deviation of the transport speed increasing also the risk of delay during winter road conditions by 5-10% and the total risk of delay by 0.5-1%. The increased transport time would have significance only when the logistics activities have developed to the level where small delays wouldn't be covered by elasticity in the logistics chain.
- Discontinuing the salting almost totally increased the costs of winter maintenance of a busy road (6 000 vehicles/day) even by 50%. The costs of winter maintenance were increased also on roads with less traffic but the effects were smaller than on the busy roads.
- Wet, including salty, road conditions existed for 46-49% of the winter period in coastal area and central Finland. The percentage of frost and icy road conditions in winter time was 11-13% except in northern Finland where the percentage was about 20%.
- Hard packed snow wore twice as fast in the studded tyre tracks than in the control tracks as measured from the cross section areas. Softer packed snow wore at the same speed both in studded tyre and control tracks.
- Two locked brakings of trucks on a road surface covered with packed snow collapsed the deceleration values. On the side of studless winter tyres deceleration values decreased by 53% and on the side of studded tyres by 36%.
- The introduction of light studs would decrease rutting to 40-50% and the forbiddance of studs to 20-30% of the current rutting level.
- The effect of alternative stud wears on maintenance costs was studied using the pavement management system (PMS). The long term target level of maintenance costs is 102 million US\$/a based on the current rutting levels. The introduction of light studs and friction tyres would decrease the maintenance costs by 17 million US\$/a. The banning of studded tyres would decrease the costs by a further 8 million US\$/a. As the current situation will anyway change towards the light stud alternative on account of the current stud regulations, the ultimate effect of a stud ban would be only about 8 million US\$/a.
- In bridge maintenance the additional annual costs caused by winter salting are about 6 million US\$ and the additional costs of corrosion damage prevention in the construction of new bridges are about 2 million US\$/a bringing the total up to 8 million US\$/a.

## VEHICULAR COSTS

- The fuel consumption of a car on a slippery, snowy and uneven road increases by 15 % compared to the consumption on a dry, bare and even road. The changes in consumption depending on road geometry are greater than those depending on road conditions.
- The fuel consumption with studded tyres is 1,2% greater than with studless winter tyres.



- The annual corrosion costs were calculated as 160 US\$ per car. With the current passenger car base the total corrosion costs are about 300 milj.US\$/a, half of it is caused by salt. The amount of salt used has a distinct effect on the corrosion costs and regional variations are great. In the calculations of total social costs the corrosion costs of cars were instead based on the protection costs and the costs were about a half of the former.

## ROAD USER EXPERIENCES

- In other countries, foreexample in Japan, the greatest disadvantage of studed tyre use was perceived to be the particle dust caused by the studs. Thus far the experiences from the winter traffic in Japan show no "alarming" signs after the move to studless winter tyres.
- In Finland in spite of rains, slipperiness and packed snow the drivers of heavy vehicles estimated the road conditions rather as fair than as bad.
- 63% of the bus drivers and 83% of the lorry drivers did not think that reduced salting impeded staying on schedule. Only 1% thought that reduced salting had hindered them quite often
- The small amount of road salt experiment in the Province of Kuopio was welcomed by the public. The experiment increased the number of people opposed to the use of salt. The use of road salt was most often opposed due to the environmental inconveniences. As expected, the representatives of the heavy traffic had a more positive attitude towards the use of road salt than the drivers of private cars. They motivated this with the increased traffic safety. The road users did not feel that the decrease in the use of road salt caused any great inconvenience. On the contrary, the attitudes of driver responsibility and driving comfort were usually increased.
- The acceptance of the future scenarios specified in the Road Traffic in Winter -programme was tested using the weighting from a conjoint study. Normal road users saw that the primary alternative was very limited salt use combined with the current studed tyres and the current level of winter speed limits. As the use of salt would be decreased from the present, the environmental influences and car depreciation would be on a lower level. The top management of the Finnra preferred 50% salting from the beginning, the current policy of tyres and changing speed limits. Traffic safety and environmental issues would be emphasised, but the salt content of ground water could increase within the recommended levels and car depreciation could continue at the current level. Environmental and traffic safety experts saw reduced salting and current studed tyres as the primary alternative. They also hoped for lower winter speed limits and increased traffic safety.

## FOREWORD

This report is a summary of the publications made in the Finnish National Road Administration's (Finnra) Road Traffic in Winter research programme of 1992-1995. The purpose of the Road Traffic in Winter research programme was to find out the most preferred combination of studded tyre use and road salting in winter from the social point of view. Nearly fifty studies were completed during the project including the progress and final reports. This report is a summary of the abstracts and summaries aimed primarily for the use by researchers and other experts wishing to obtain a general view of the extent and versatility of the research programme.

The report has been composed by senior research scientist Kari Alppivuori of Communities and Infrastructure at the Technical Research Centre of Finland. Senior research scientist Kari Mäkelä, research engineer Matti Anila and project secretary Eeva-Liisa Ryyänen of Finnra Savo-Karjala region have also participated in the making of the report.

The representative of the Finnish National Road Administration in the making of this report was Ms Anne Leppänen, the project manager of the Road Traffic in Winter research programme.

Helsinki September 1995

Traffic services  
Road traffic in Winter -research programme

Anne Leppänen  
Project manager

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## CONTENTS

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1 INTRODUCTION	11
2 SOCIAL OPTIMIZATION	12
3 TRAFFIC SAFETY	17
3.1 Winter tyres	18
3.2 Driver behaviour	24
3.3 Reduced use of salt	29
4 ENVIRONMENTAL EFFECTS	31
4.1 Ground water	32
4.2 Vegetation	38
4.3 Dust	39
4.4 Alternatives to road salt	41
5 MAINTENANCE	43
5.1 Winter maintenance	44
5.2 Pavements	47
6 VEHICULAR COSTS	52
7 ROAD USER EXPERIENCES	54

## 1 INTRODUCTION

ROAD TRAFFIC IN WINTER was a the Finnish National Road Administration's (Finnra) research programme in the years 1992-1995 in which the social and economical effects of salting and studded tyres were extensively studied in the view of the road authority, road user and environment.

The Road Traffic in Winter programme was drafted in the winter of 1990-1991 by working out a preliminary research programme (Kallberg & al. 1991). The programme was developed further in the Finnish National Road Administration and the actual studies were launched in the autumn of 1992. The essential objective of the study was to investigate the effects of reduced salting and studded tyre use (in Finland all four tyres had to be studded if studded tyres are used) compared to the existing situation. The basis was the road maintenance policy of that time. Public discussion of environmental issues and the suspicion of the detrimental effects of road salt succeeded in changing the winter maintenance policy towards less salt even during the Road Traffic in Winter programme. At the same time, the effects of the changed studded tyre regulations (the maximum weight of a stud was reduced from 1,8 g to 1,1 g) were becoming apparent.

All of the effects have been converted into costs. The calculated costs and values are at best estimates of magnitude and trend.

Kallberg Veli-Pekka & al.: Talvi ja tieliikenne- Tutkimusohjelma. (Road traffic in Winter, preliminary research programme). Espoo 1991. Technical Research Centre of Finland, Research Notes 1308. ISBN 951-38-4041-7, ISSN 0358-5085.

**Keywords:** traffic safety, traffic ability, traffic surveys, winter, cold weather operations, road surface, research programmes, future, snow removal, recommendations, economic analysis, maintenance, cost effectiveness, environments, studded winter tyres, vehicles, inorganic salts.

The general aim of this preliminary research programme was to increase knowledge of road traffic problems caused by winter conditions and to explore future solutions. The central purpose was to determine existing (1990) and future research needs and suggest future directions in this field.

A preliminary research programme was proposed based on the framework of five different scenarios about future developments in road traffic in winter. Research projects that would result in resolutions to problems of winter driving and road maintenance were described for each scenario with emphasis on resolutions that would be acceptable and cost-effective.

The effects of winter conditions (especially snow and ice) on road traffic were systematically described in a comprehensive framework. The main components of this framework included vehicle, time, accident, road maintenance and environmental costs and various combinations of factors affecting these costs.



## 2 SOCIAL OPTIMIZATION

Alppivuori Kari, Kanner Heikki, Mäkelä Kari & Kallberg Veli-Pekka: Nastarenkaiden käytön ja talvikunnossapidon yhteiskunnallinen optimointi. (The socio-economic effects of winter maintenance in the ROAD TRAFFIC IN WINTER-programme) Helsinki 1995. Finnra 4/1995. ISSN 0788-3722, ISBN 951-726-081-4, TIEL 3100019.

This study summarises the socio-economic effects of the ROAD TRAFFIC IN WINTER- programme, which was carried out by the Finnish National Road Administration (Finnra) in the years 1992-1995. The salting of roads and the use of studded tyres during the winter season were studied in order to find the most favourable combination from a socio-economic perspective. The aim was to determine the various effects on the environment, traffic safety and other factors in alternative scenarios of studded tyre usage and road salting.

Altogether there were nine different scenarios, representing permutations of three different usages of studded tyres and three different salting alternatives. The alternative salting regimes were: full salting (120 000 tonnes p.a.), 50% reduced salting and 80% reduced salting. The alternative usages of studded tyres were the baseline usage, i.e. 95% passenger cars fitted with studded tyres, 50% usage and less than 20% usage.

The baseline situation, i.e. 120 000 tonnes p.a. of salting and 95% of passenger cars fitted with studded tyres, was representative of the actual practice at the commencement of the project in 1992. Since then, the salting of roads has been reduced somewhat and light-weight studs that are less abrasive to pavements are now used in new snow tyres. It is assumed in the calculations that all studded tyres in use conform to the latest requirements with regard to light-weight studs (1.1 g.).

In the socio-economic calculations, efforts were made to take account of the effects as broadly and as comprehensively as possible. The calculations include the costs of the road authority, the motorist, society as a whole, and the environment. Cost assessments are based on the costs of preventing harmful effects, the established practice (e.g. accident costs) or, in the absence of these, the best estimates of relevant experts. Because of the methods employed, the intrinsic value of natural resources such as groundwater or the landscape<sup>1</sup> were not taken into account in the calculations. If these factors had been taken into consideration, the costs of the various scenarios would have risen. On the other hand, the emphasis from the socio-economic perspective would hardly have changed at all, since the effects partially cancel each other out.

The costs and assessments are based on 1992/1993 prices, inclusive of taxes. In some cases the annual costs of previous years were used when more precise data were not available. Changes in the value of money were not taken into account, since inflation has been minimal in recent years and the calculated costs are, at best, good estimates.

The socio-economic comparison deals with roads maintained by Finnra. However, motorways and slip roads were excluded, since it was assumed they would be unaffected by any salting policy changes. Altogether 77 000 km of roads are included in the comparison. Of these, approximately 7 000 km are salted through the years and the remainder gritted. The policy changes in winter road maintenance are reflected mainly in the salted roads. Urban streets are maintained by the municipalities. If Finnra were to change its policy on winter road maintenance, probably the municipalities would not follow. On the other hand, changes in the usage of studded tyres would affect the street network, so these effects were taken into consideration, for instance, when calculating accident costs. Possible changes in tyre usage which might bring changes in winter maintenance were not considered in the comparison.

### **Traffic safety**

The point of departure for the changes in traffic safety were the number of vehicle-kilometres driven on slippery road surfaces and the accident risk in different road conditions. The findings of the study indicate that all the alternatives concerning reduced road-salting and the reduced use of studded tyres would lead to an increase in the number of accidents. Reducing the level of salting by 50% would lead to a 6% increase in winter-time accidents involving bodily injuries. Similarly, reducing the use of studded tyres by 50% would increase such accidents in the winter season by 10%. The greatest effect on bodily injury accidents would occur in the scenario of 80% reduced salting and less than 20% of passenger cars fitted with studded tyres. In that case, bodily injury accidents during the winter season (1.11.-31.3.) would rise by about 30%. Converted into economic costs, the value of the traffic safety changes in the various scenarios range from US\$ 44 million to US\$ 222 million Per annum.

### **Environment**

Environmental impacts were reasons prompting a study on the effects of reducing the level of road salting in the winter maintenance policy. The worst drawback is the accelerated corrosion of water pipes caused by chloride. The technical-aesthetic value assigned on the basis of corrosion effects in Finland is 100 mg/l and the target value less than 25 mg/l, which is also the standard required by the European Union.

The annual costs of protecting aquifers over a ten-year period are calculated at US\$ 7-15 million, depending on the scenario. The upper value of the range represents the baseline situation. Protective measures cannot entirely prevent salt from entering the groundwater, although the drawback can be lessened. In all of the scenarios it is assumed that technical means are employed to keep the salt applications as small as possible. The difference between the various scenarios is largely due to the extent of the salted road network. The effects of salting on roadside vegetation is minimal, being limited to less than 20 metres on either side of the carriageway.

Road dust originates from road salt, the pavement, exhaust gases and, above all, from grit. Gritting and the use of studded tyres makes road dust



particularly problematic in the spring. Although road dust is a considerable problem for people living in built-up areas, it is only significant on a small proportion of the roads maintained by Finnra.

Changes in the winter road maintenance policy have effects on the noise level as the wetness of the road surface and the speed driven by vehicles change. Reducing the use of studded tyres also reduces road noise. The level of noise and thus the value of noise disturbance is reduced in all the examined scenarios. However, the value of the noise change was not taken into account in the calculation of environmental impacts, since it cannot really be determined, for instance, by equating it with the costs of preventative measures.

### **Corrosion**

The corrosion of vehicles has been cited as an important reason for reducing the salting of roads. The costs of preventing vehicle corrosion were used in this study to determine the value of the corrosion drawback, and it was accepted that vehicles need not be entirely free of corrosion at the end of their service lives, since they may also be withdrawn from use because of ageing or some other technical deficiency. The value of corrosion damage to vehicles calculated on the basis of the costs of preventative measures would be reduced by US\$ 63 million per annum if the amount of salting were reduced by 80%. If salting is reduced, gritting must be increased accordingly. This would increase the amount of damage to vehicle paintwork and windshields. At their largest, the changes were valued at about US\$ 7 million per annum.

### **Maintenance**

As recently as in the 1980s pavement wear was significant, mainly due to the use of studded tyres. In the 1990s, largely as a result of Finnra's ASTO Pavement Research Programme, new types of pavement that are more resistant to studded tyre wear have been developed. Furthermore, regulations concerning studded tyres have been changed so that the maximum stud weight has been reduced from 1,8 g to 1,1 g. These developments have essentially reduced the wear of pavements. If one assumes that all the roads are surfaced with the more wear-resistant pavements and that most motorists use studded tyres conforming to the new stud weight regulations the increase in annual pavement costs caused by studded tyre wear would be no more than approximately US\$ 7 million per annum.

The costs of winter road maintenance (baseline situation approx. US\$ 89 million p.a.) will increase if the salting of roads is reduced. Similarly, the costs of winter road maintenance will increase if the number of cars fitted with studded tyres falls. The increase in costs is less than 10% in most cases. In a situation where salting is reduced by 50% or 80% and less than 20% of cars are fitted with studded tyres, the costs of winter road maintenance would increase by US\$ 16 million or US\$ 44 million, respectively. The growth in costs is due to an increase in the amounts of snow-ploughing, levelling and gritting.

## Driving comfort

When judging driving comfort, motorists said during interviews that they liked driving on unsalted roads. As, however, even in wintry conditions, salting results in most cases clear, dry road surfaces with only a relatively short period of wet conditions which the motorists value, no assessable change in driving comfort was regarded as occurring in any of the scenarios.

## Other effects

Tyre and car-washing costs, including the costs of windshield washing liquid, bridge corrosion costs and the maintenance costs of different types of road side equipment were all taken into account in this study.

The final result is obtained by aggregating all the socio-economical costs without emphasising any single component more than any other, Figure 1.

### ROAD TRAFFIC IN WINTER-SCENARIOS

#### CHANGE IN TOTAL COSTS COMPARED TO THE BASIC SITUATION

Changes in total costs Million US\$/a	Salt 120 000 t/a	Salt —50%	Salt —80%
Studded tyres in 95% of cars	basic situation	36	36
Studded tyres in 50% of cars	47	91	98
Studded tyres in 20% of cars	100	160	202

Figure 1. Summary of the socio-economic costs of the various scenarios examined in the ROAD TRAFFIC IN WINTER- programme.

None of the examined scenarios was more favourable than the baseline situation. As road salting has actually been reduced since the baseline situation (120 000 tonnes p.a.) was representative of current practice, i.e. 1992, socio-economic costs have risen. The findings of the study indicate that the optimum economic state for winter maintenance is either the baseline situation or beyond the scope of the scenarios examined. The findings also suggest that the use of salt in winter road maintenance should be increased rather than reduced. On the other hand, it should be stated that the environmental impact of road salting cannot be allowed to increase above the present level. However, developments in salting techniques mean that small amounts of salt are now able to yield almost the same quality of road surface as that requiring large quantities of salt in the early 1990s.

Different interest groups will all find grounds to criticise the findings of the study, since the best alternative for the future will depend on the perspective from which the facts are examined. From the perspective of the motorist, roads without salt and tyres without studs offer the most favourable alternative, unless the increased accident costs are borne by motorists through higher insurance premiums, which would seem likely if this alternative were to be adopted.



From the perspective of the road authority, reducing the use of studded tyres and the amount of salt from 120 000 tonnes p.a. by a half would be the most favourable option. One significant factor favouring the reduction of salting, as far as the road authority is concerned, is the reduced need to protect groundwater resources. Reducing the use of studded tyres would cut the costs of pavement repair and road markings. Almost completely doing away with salting would increase the costs of the road authority because of gritting and the need to eliminate the dust that it causes.

From the perspective of the environment, reducing the use of salt and studded tyres is favourable. Surprisingly perhaps, the zero salt/stud alternative is not the best even from the environmental standpoint, because then the drawbacks of dust from gritting increase significantly.

When searching for the socio-economic optimum, the accident costs become the most important factor. These costs are really huge in the zero salt/stud alternative. The accident costs strongly support retention of the baseline situation i.e. the use of salt and studded tyres should be continued in spite of their drawbacks. Studded tyres provide added safety, especially for uncertain drivers in variable road conditions. Similarly, salting evens out variations in road conditions and provides an opportunity to travel safely and smoothly even in the winter.

This study has provided simplified answers to complex questions. All of the values were difficult to express in monetary terms. Those intending to utilise these findings should also familiarise themselves with more detailed studies, which will provide a more comprehensive view of the complexities of the field.



### 3 TRAFFIC SAFETY

#### TRAFFIC SAFETY STUDIES IN A NUTSHELL

##### TYRE RESEARCH STUDIES

- The condition of the tyres does not affect the speeds in winter time. The drivers who thought their tyres were inferior did not drive slower than others.
- The drivers' knowledge about the condition of their tyres was poor and their knowledge about the condition of their studs was even worse.
- The grip of the new light studs is quite similar to that of the older steel studs, but the wear of pavements is only about half. The serviceable life of the light studs varies considerably between different makes.
- Studded tyres as a whole are better than friction tyres. A car equipped with ABS brakes and friction tyres is a good combination if driving under icy conditions can be avoided.

##### DRIVER BEHAVIOUR

- The change to friction tyres did not affect the amount of driving. Drivers with friction tyres drove slower than those with studded tyres in built-up areas and at sharp curves. They also maintained a longer safety margin to the car in front. The changes were not, however, sufficient to keep the risks at the same level as the drivers with studded tyres. Otherwise the change to studless winter tyres did not affect driving speeds in adverse road conditions.
- In good road conditions the increase in speed of the friction tyre users can have a negative effect on traffic safety.
- As age and driving experience increase the risk of minor accidents decreases, but particularly the risk of severe accidents is at its greatest for young and old drivers.
- Drivers are not aware of the road conditions. The road conditions are usually evaluated as less slippery than they really are. On the other hand the condition of the tyres is overestimated. Under slippery conditions, over half of the drivers (56%) estimated the conditions non-slippery or semi-slippery. Very slippery road conditions were deemed by 13% as non-slippery and only by half of the drivers as slippery or quite slippery.
- Although the road conditions are considered as slippery, people do not change their driving behaviour sufficiently and the risk increases. In snowy conditions speeds decrease by 4-5 kmph and in slippery conditions by 3-7 kmph.
- Drivers seem to take the winter speed limits as a "recommended speed" regardless of how slippery the road surface is.
- Drivers in queues do not keep adequate safety margins (headways). This is a problem especially in the capital region. In winter conditions one in every four keep too small headways (under 1,5 sec).



- Studded tyres in good condition increase safety. When studying fatal accidents, 30% of the tyres were classified as being in bad condition (in normal traffic the percentage is 3%).

#### REDUCED SALTING EXPERIMENTS

- During the reduced salting experiments in Kuopio region the amount of sanding tripled. As small amounts of salt were used in the sand to enhance adhesion, the total amount of salt was reduced by 80%.
- On the experimental roads, friction levels below 0,3 were twice as common as on control roads. Less than 3% of the time the friction levels were below 0,2 with no difference between experimental and control roads.
- The number of injury accidents on the experimental roads was 27 in the first winter and 25 in the second winters, which was about the same as the average during the five-year period before the experiment (26.8). Because the trend on control roads was decreasing the calculated effect of reduced salting was an approximate 5% increase in the number of injury accidents. On roads with traffic volumes below 6 000 vehicles/day, that contained more than 80% of all experimental roads, the increase was about 20%. This equals to four injury accidents each winter. The number of fatal accidents, however, did not increase.

### 3.1 Winter tyres

Antila Jukka, Mäkelä Timo, Heinijoki Heikki & Saastamoinen Kimmo: Talvirengastutkimus. Talvirenkaiden kulumis- ja kitkaominaisuuksien vertailu sekä talvirenkaiden käyttö ja kunto talvikaudella 1993-1994. (A survey of winter tyre wear and skid resistance and the use and condition of winter tyres in the winter of 1993-1994). Helsinki 1994. Finnra 34/1994. ISSN 07883722, ISBN 951-47-9422-2, TIEL 3200243.

**Keywords:** winter tyre, studded tyre, studless winter tyre, stud, protrusion, tread depth, braking distance

This report is a compilation of the results of two projects. The first employed seven Nokia Hakkapeliitta 10 tyres fitted with different types of commercially available studs, in order to determine their effects on skid resistance as a function of distance driven, together with examples of the four most commonly available studless winter tyres, for assessment of their wear and skid resistance properties. All the tyres were used for 50 000 km of steady driving on main roads in January-March 1994, with braking tests on smooth ice at 10 000 km intervals. Their tread depths and stud protrusions were measured before each of the braking tests.

Three vehicles were used for the experiment, and one specimen of each tyre to be studied, the tyres being circulated between the vehicles and exchanged between the axles to ensure equal use. The braking tests were carried out by the 'one-wheel method'. The studs tested were types Kometa P8-110, MIBA 8-11/1, Nesspike 711/3, Nesspike WIP, Scason 8-11 alu, Tikka



H8-11/K and Turvanasta L 42, and the studless winter tyres Bridgestone Blizzak, Goodyear UG 4, Michelin XM+S 100 and Nokia NRW.

Wear on all the tyres as a result of the driving on main roads was low, the tread depths on the studded tyres being reduced by an average of 1.5 mm, i.e. they had 84% of their original tread depth remaining. Wear on the studless winter tyres varied in the range 0.9-2.2 mm, i.e. 88-76% of their tread remained after 50 000 km.

All the stud protrusions were reduced in the test, but there were great differences between them in the extent of this effect. In the first test, because of the driving circumstances, the tread of tyres did not wear but studs did. That's why we had another test next year and in different circumstances including more city driving.

Stud wear was assessed by removing 24 studs from each tyre at the end of the experiment and comparing their lengths with those of the original 11 mm studs. The wear of studs in 50 000 km was 1,4-3,0 mm.

Mean road conditions altered greatly in the course of the experiment. Most road conditions were icy or partially icy in January and early February, while 7% of the distance in March was driven on entirely bare roads. This brought about an evident increase in tyre wear. The changes in road conditions did not appear to have an affect on stud protrusions, however.

It was also designed to examine the use and condition of winter tyres in practice. Measurements were made at the end of January and beginning of February 1994 in four towns, Rovaniemi, Kuopio, Vaasa and Helsinki, at the same parking places as had been used in a previous survey in winter 1992-1993. The tyres on a total of 1603 vehicles were examined during the winter of 1993-1994.

The 1993-1994 measurements showed that almost 100% of all private cars and vans were fitted with winter tyres (M+S tyres), 93.8% with studded tyres (95.1% in winter 1992-1993) and 5.9% with studless winter tyres or friction tyres (4.5% in 1992-1993). Only 0.3% had summer tyres (0.4% in 1992-1993). The increase in the proportion of studless or friction tyres was statistically significant at the 5% confidence level.

The use of studless winter tyres on private cars was most common in the Helsinki area (3.1%) and least so in Vaasa (0.3%). The proportion of vans with tyres of these types was very much higher than that of private cars (14.7% vs. 4.9%). The proportion of new tyres on the vehicles was 21.7% (24.4% in 1992-1993) and that of excessively worn (illegal) tyres 1.8% (2.8% in 1993-1994). Thus the economic recession was not reflected in the over-use of tyres. The proportion of studded tyres with new studs was 19.0% (18.5% in 1992-1993) and that of badly worn studs 8.8% (9.7% in 1992-1993).



Heinijoki Heikki & Mäkelä Timo: Talvirengastutkimuksen täydennysosa. Nasta-renkaiden ja kitkarenkaiden kulumisvertailu maantie- ja kaupunkiajossa sekä renkaiden kitkaominaisuuksien vertailu. (**Supplement to the winter tyre report. Comparison of wear on studded tyres and studless tyres in main road and town use and comparison of their friction properties**). Helsinki 1995. Finnra 22/1995. ISSN 0788-3722, ISBN 951-726-055-5, TIEL 3200300.

**Keywords:** winter tyre, studded tyre, studless tyre, stud, protrusion, tread depth, braking distance, acceleration

The paper discusses changes in the grip of studded tyres and friction tyres (studless winter tyres) in ordinary driving, i.e. in driving which causes ordinary wear and stud protrusion. The total driving distances was 40 000 kilometres, of which a half was on main roads and a half on urban streets.

Tyres with two types of studs and two types of friction tyres were used in the tests. The studded tyres were of the type Nokia Hakkapeliitta 10 with Kometa or Nesspike WIP studs and the friction tyres Bridgestone Blizzak and Nokia NRW. These represent the most common studded and friction tyres available in Finland.

The wear test involved sequences of 5 000 kilometres of driving distributed equally between urban streets and main roads. The tyres were circulated between the vehicles and exchanged between the axles to ensure equal wear. The majority of the 40 000 kilometres was driven on snow-free surfaces (35% dry and snow-free, 24% snow-free, but wet), with 23% taking place on snowy surfaces and approximately 9% on icy roads and as well as on partly snowy surfaces. The distribution of driving conditions fairly well describes the situation on Finnish roads during winter time.

Changes in the friction properties of the tyres were monitored by means of grip tests conducted at intervals of 5 000 kilometres. Tread depths and stud protrusions were measured before the tests and these together with stud wear afterwards. The first grip test were conducted after running the tyres 1 160 kilometres.

The grip tests involved braking with locked wheels and accelerations on smooth ice and packed snow. The final grip measurements also involved examination of lateral grip properties of the tyres on both surfaces mentioned before.

The tread depth measurements indicated that there were no appreciable wear differences between the tyres on the left and right sides of the vehicle. The Bridgestone Blizzak tyres showed by far the greatest total wear after 40 000 kilometres, i.e. 4.2 millimetres, being more than twice that of the Nokia NRW friction tyres (total wear 2.0 millimetres). The wear on the tyres with the WIP studs was 2.3 millimetres and those with the Kometa studs 2.2 millimetres.

A pronounced difference in protrusions were observed between the Nesspike WIP and Kometa studs at the beginning, but that of the former increased markedly during the first 5 000 kilometres to reach the same level as the

latter, a trend which is very common with vehicles that are in active use. No appreciable changes in stud protrusion were observed in the middle periods of testing, and the largest protrusions were found after 20 000 kilometres for both studs, after which they began to decline. The protrusions of the Kometa studs declined particularly markedly during the final 10 000 kilometres.

Of the four studded tyres used in the wear tests, three lost some studs during the test, two of them only losing a single stud each but the remaining one, which suffered a puncture before the end of the test, losing a total of 13 studs. The test was found to strain the studs on the right side of the vehicle most. In addition, a major difference in wear was observed between the Kometa and WIP studs in this respect, the wear of the former being 2.2 millimetres and that of the latter 1.6 millimetres. Wear on both types of stud was most marked on the inner parts of the tread in every case.

The studded tyres had a markedly better grip on smooth ice than the friction tyres throughout the test, but particularly in the middle of the test periods, when braking distances of the friction tyres were 55-60% longer than those of the studded tyres. In addition, the studded tyres maintained a good grip up to 25 000 kilometres, followed by a noticeable decline. Although the studs were partially worn-out after 40 000 kilometres, their grip properties were still markedly better than those of the friction tyres.

One factor which could not be taken into consideration in the results from grip tests on the smooth ice was the fact that the rubber mixture tends to age, with a consequent decline in its grip properties. This would most probably have meant that the grip difference between studded tyres and friction tyres in the above results would have become even more pronounced if the study had been lasted longer.

The grip tests conducted on packed snow indicated that there are no differences for practical purposes between the grip properties of studded tyres and friction tyres on snow, as only minor grip differences and fluctuations were observed at the various stages in the study.

Saastamoinen Kimmo & Heinijoki Heikki: Talvirengastutkimus. Talvirenkaiden käyttö ja kunto sekä kuljettajien arviot talvirenkaistaan talvikaudella 1992-93 (Winter tyre research. The use and condition of winter tyres and drivers' own evaluation of their tyres, winter 1992-93). Helsinki 1993. Finnra 45/1993. ISSN 0788-3722, ISBN 951-47-7685-2, TIEL 3200170.

**Keywords:** winter tyre, studded tyre, studless tyre, protrusion, rut depth, condition

Information on the use and condition of winter tyres was collected by examining tyres in parking places in Rovaniemi, Kuopio, Vaasa and Helsinki and through roadside interviews conducted in nine road regions. The latter also involved the drivers' own evaluation of the condition of their winter tyres. A total of 8300 vehicles were examined during winter 1992-93 and personal evaluations were obtained from 3 300 drivers.



Attention was paid to the extent to which studded tyres and studless tyres were used, condition of the tyres and studs throughout the winter period, differences between front and rear tyres in this respect and the distribution of the tyres between manufacturers. The investigation also covered the types and numbers of studs employed and various measures of stud protrusion.

Almost 100% of the tyres used on cars and vans in winter 1992-93 were winter tyres, of which 94,6% were studded and 4,7% studless (including studless, i.e. friction tyres). Summer tyres amounted to 0,6%.

No regional differences were observed in the use of studded tyres. They were slightly more common on cars than on vans, the most common stud type being the traditional steel stud, which was used on 95% of the tyres examined, as opposed to light-weight studs, for which the figure was 4 to 5 %.

54% of the drivers interviewed were able to evaluate the condition of their winter tyres correctly, while 41% of the evaluations deviated from the measured results by one category and 5% markedly, i.e. by 2 to 3 categories. One driver in 50 was incapable of contributing any evaluation of his tyres.

Persons driving less than 10 000 km or more than 65 000 km a year were slightly less aware of the actual condition of their tyres than the others. Persons using a car on a regular basis were able to make more accurate evaluations than those using a car only occasionally. No appreciable differences were observed between men and women in this respect.

Condition evaluation was found to be the more difficult the poorer the actual condition of the tyres was, as indicated by the fact that almost 50% of the drivers with excessively worn tyres considered their tyres good or as good as new.

The drivers were somewhat less aware of the actual condition of their studs than that of their tyres. A fair statistical correlation was observed between the evaluation and measurements, however.

Alppivuori Kari & Anila Matti, 1994. Kitka- ja nastarenkaiden pito-ominaisuudet eri keleillä. (Friction tyres and studded tyres in different circumstances). Finnra 68/1994, TIEL 4000098.

**Keywords:** studded tyres, friction tyres, winter tyres, friction

The grip characteristics on different winter tyres were examined under different road conditions during 1993 and 1994. The study included three studded tyre types and two friction tyre types. By friction tyres we mean winter tyres which are not meant to be equipped with studs. There were four different types of studs. There were new and 10 000 km used tyres of each type. There were six different road condition types.

The study employed the TRC (Technical Research Center of Finland) friction metering lorry and Peiseler equipment. Other supplementary measurements were also included in the study. The measurement methods and complete measurement results are included in report no. 221.

The main problem of winter driving is the quick variation of road slipperiness. According to traffic volumes, 10% of winter driving in southern Finland takes place under slippery conditions. In northern Finland the percentage is 20. When the friction level is over 0,25 the grip of the tyres can be considered very good for winter driving. The friction level for moderate driving is 0,20. When the level drops below 0,15 winter driving requires good co-operation between the driver and the tyres.

The lateral grip on packed snow was good for all tyre-stud combinations both new and used.

On dry ice the lateral grip of tyres with new aluminium (current regulation 1,1 g) studs was poor. The grip was even worse with studs made according to the older regulations (1,8 g). As the slip angle steepened the lateral grip on dry ice got extremely poor.

During locked braking on packed snow the grip of studded tyres was poor and the grip of friction tyres extremely poor. During these conditions the grip of the older regulation tyres with large stud protrusion was very good.

During locked braking on dry ice the grip of current regulation tyres with aluminium studs were between poor and extremely poor. Other studded tyres were always extremely poor. Friction tyres had no grip at all.

During very slippery road conditions all studied tyres have vehicle control problems. The difference between studded tyres, especially with the current regulation aluminium studs, and friction tyres is that a side or braking slip in slippery conditions can be better controlled and negotiated with studded tyres. A car with friction tyres can get out of control in a slip.

A car equipped with ABS equipment and friction tyres is a good combination if it doesn't have to be driven in icy conditions. As a whole, studded tyres are better than friction tyres. The difference between new and slightly (10 000 km ) used tyres is still insignificant.

Tyres with current regulation aluminium studs had generally better grip than tyres with older regulation or other types of studs.



### 3.2 Driver behaviour

Roine Matti: Kuljettajakäyttäytyminen kaarre- ja jonoajossa. (**Driver behaviour in sharp curves and queues on main roads**). Helsinki 1993. Finnra 87/1993, ISBN 951-47-877-4, ISSN 0788-322. TIEL 3200212.

**Keywords:** driving behaviour, road safety, accident risk, road condition.

The investigation deals with driver behaviour while driving in queues and in sharp curves during winter-time with studded and with studless winter tyres. The measurements of driver behaviour focused on driving on slippery road surface condition. The drivers were stopped for interviews after the measurements of driver behaviour. During the interviews also the type and condition of tyres and studs were recorded.

Both locations where speeds of drivers in sharp curves were studied were situated in the capital region. Driver behaviour on a normal main road in queues was studied in the Kuopio region. Driver behaviour in queues indicated the speeds and headways of drivers with studded and studless winter tyres in traffic flow condition.

The estimated average speed of the drivers was about 6 km/h lower in sharp curves on slippery compared to dry or wet road surface condition. However, the headways were significantly lower on slippery curves pointing out that decreasing friction level seems to increase the accident risk of drivers. Speed models implicated that studded drivers drove with somewhat higher speeds in curves than drivers with studless winter tyres. However, there were no major differences in the average safety marginals between studded and studless winter tyre drivers.

Variance of the coefficient of friction did not have any great influence on driver speeds on main roads whether driving in queues or not. The average speed of studded tyre drivers in queues on main roads was a little higher than the speed of drivers with studless winter tyres. There were no statistically significant differences in the average headways of drivers in queues in different road conditions. The average headway of the studless drivers was somewhat smaller than the studded tyre drivers.

Around 20-30% of the drivers in queues on main roads drove with so small headways that unexpected braking situations would cause dangerous incidents and perhaps also lead to accidents.

Mäkinen Tapani: Nastarenkaiden vaikutus matkoihin ja kuljettajien riskinottoon; kuljettajavertailu, väliraportti. (**Effects of studded winter tyres on trip making and risk taking, results of the first year**). Helsinki 1994. Finnra 1/1994. TIEL 4000054.

Look at the final report below.

Mäkinen Tapani, Beilinson Leif, Rathmayer Rita & Wuolijoki Arja: Nastarenkaiden vaikutus matkoihin ja riskinottoon. (**The effect of studded tyres on journeys and driver risk taking**). Helsinki 1994. Finnra 64/1994. ISBN 951-726-010-5, ISSN 0788-3722. TIEL 3200273.

**Keywords:** instrumented car, driver behaviour, winter traffic, tyres

The object of the study was to investigate how drivers' behaviour is changed when they start to use studless winter tyres instead of studded tyres. The study took two winters from 1992 until 1994.

There were randomly selected 120 drivers from the register of vehicles. Of the two matched groups the other one was given studded tyres for their own cars and the other group received studless winter tyres. The dependent variables were effects on exposure such as number, length, timing of trips in urban and outside urban areas. Also driving speeds, use of brakes and keeping headways were monitored.

Exposure related variables were studied by using driving logs which were kept during eight specified weeks in the course of the two test winters. Driving logs covered the exposure of more than 360 000 kilometres altogether.

Driving behaviour was monitored through two identical instrumented cars. 68 drivers participated in this part of the study. Those using studded tyres on their own cars were driving the instrumented car equipped with the studded tyres and those having studless winter tyres were driving the instrumented car with studless tyres respectively. The subjects drove the route of about 80 kilometres consisting of various road types three times, twice in the first winter and once in the second winter. In addition to speeds, the computers in the cars registered the use of brakes and headways. The instruments were hidden in the cars and the purpose of the study was not revealed to the drivers until after the last driving task.

Analysis of the driving logs show that changing to studless winter tyres didn't affect exposure such as number of trips at all nor the use of other transportation modes.

During the first winter driving speeds of studless tyre drivers increased especially in good driving conditions on motorways. However, on sharp curves drivers with studless tyres slowed down more than those using studded tyres. Moreover, on slippery secondary roads studless tyre drivers were using brakes more softly than control drivers with studded tyres.

During the second winter the speeds of studless tyre drivers returned mainly to the before-level when both the groups were using studded winter tyres. Studless tyre drivers were, however, still negotiating steep curves more carefully than control drivers. Moreover, the speed level of studless tyre drivers were lower in urban areas than that of studded tyre drivers. Also headways of both the groups were monitored in the second winter. It turned out the studless tyre drivers were keeping 11 meters longer headways on an average than control drivers.



The results of the study suggest that turning to studless winter tyres doesn't change driving speeds markedly in the long run. On the other hand, drivers using studless tyres drive somewhat more carefully in conditions which they experience difficult or demanding more attention than driving on the main road network or in urban areas. The changes were not, however, sufficient to keep the risks at the same level as the drivers with studded tyres.

Drivers using studless tyres were very pleased with the change. None of them wanted anymore change back to studded tyres. Every fourth driver using studded tyres reported to consider to start using studless winter tyres. This all suggests that the share of studless winter tyres will increase in winter traffic when drivers gain more experience of them.

Roine Matti: Nastattomia talvirenkaita käyttäneiden kuljettajien onnettomuusriskit. (**Accident risks in winter traffic among drivers using studless winter tyres**). Helsinki 1994. Finnra 69/1994. ISBN 951-726-017-2, ISSN 0788-3722, TIEL3200278.

The aim of this study was to examine the accident risks of drivers during the winter months and especially to compare the safety of the drivers using studded and studless winter tyres. The basic research data was collected by questionnaire addressed to 10 000 vehicle owners. Data on fatal accidents gathered by the Road Accident Investigation Teams during 1987-1991 was used as comparative data. In winter traffic several different factors have a bearing on the accident risks facing drivers. The amount of accidents depends on exposure and accident risks. The main risk-factors were age of driver, driving experience, gender, use of alcohol, driver behaviour, road condition, familiarity of the selected route and vehicle characteristics. Drivers using studless winter tyres had a higher relative risk than drivers with studded winter tyres. Most of these studless tyres were old studded winter tyres with the studs removed and not specific non-stud type winter tyres. This was partly due to the tyres but also due to the accumulation of risk-factors among this special and very small population of drivers using studless winter tyres. However, young drivers had altogether higher accident risks during winter months.

Saastamoinen Kimmo: Kelin vaikutus ajokäyttäytymiseen ja liikennevirran ominaisuuksiin. (**Effect of road conditions on driving behaviour and properties of the traffic flow**). Helsinki 1993. Finnra 80/1993. ISSN 0788-3722, ISBN 951-47-8139-2, TIEL 3200204

**Keywords:** driving behaviour, slipperiness, road conditions, automatic traffic monitoring system

The aim of the current investigation was to examine general driving behaviour in various parts of the country with special focus on the effects of road conditions and slipperiness on driving speed and distances between vehicles. The restriction on the use of salt on roads in Kuopio region and its effects on driving was also considered.

Driving speed was found to decline considerably as a result of wintry weather and reduced winter speed limits so that the effect of road conditions on



driving behaviour was found to be of significance only in the case of snowy weather. Winter condition and the more stringent speed limits compelled drivers accustomed to high speeds to reduce speed considerably (v85 speed level, i.e. speed below which 85% of vehicles travel), whereas the v15 level, for example, was found to decline less than the average speed. This led to lower standard deviation and a reduction in speed differences. The situation can be considered quite good from the traffic safety point of view, as the number of accidents declines with speed differences and their consequences are less severe.

Fairly prominent changes in driving speeds take places under snowy and ice conditions, as indicated by the fact that speeds were found to decline by approx. 4 km/h according to an automatic road weather information system (in November-December) and by 4-5 km/h in manual observations. The change can be considered a substantial one in that reducing the speed limit from 100 km/h to 80 km/h altered actual speeds by less than 4 km/h. Minor speed differences were observed between the regions examined, slightly lower speeds being recorded under adverse road conditions in Northern Finland, inland areas and Kuopio region than on the western coast and in Helsinki region.

Speed was found to decline in all limit zones as the roads became more slippery, by 0...3 km/h when the tyre grip was fairly good (friction 0.36-0.45), 3-6 km/h under fairly slippery conditions (friction 0.26-0.35) and 4-7 km/h under slippery conditions (friction less than 0.26) as compared with good conditions (friction over 0.45). It should be noted that speed did not change to any appreciable extent when the conditions changed from fairly slippery to slippery. No appreciable regional differences in driving behaviour were observed in slippery weather, although the results obtained for Kuopio region under slippery conditions were quite exceptional.

Distances between vehicles did not change appreciably from summer values under good (dry) conditions, but the number of headways (less than 1.5 seconds) in queues was found to decline from 38% in summer to 25% under bad conditions. Where considerable differences between the regions were observed in measurements performed in summer, the proportions of headways in queues being higher in the Helsinki region and on the coast, values were broadly similar throughout the country under adverse winter conditions.

Heinijoki Heikki: Kelin kokemisen, rengaskunnon ja rengastyypin vaikutus nopeuskäyttäytymiseen. (Influence of the type and condition of tyres and drivers' perceptions of road conditions on driving speed). Helsinki 1993. Finns 19/1994. ISSN 0788 3722. ISBN 951-47-9098-7. TIEL 3200229.

**Keywords:** driver behaviour, driving speed, road condition evaluation, driving conditions, friction, studded tyre, studless tyre.

The aim of this work was to examine the degree to which drivers take slipperiness of the roads into consideration in winter and to find out whether their evaluations of existing road conditions and the state of their tyres and actual type of tyre used (studded/studless winter tyres) and state of wear influence the speeds of cars and vans driven under varying conditions in



non-continuous traffic. The material representing varying weather conditions was collected by means of roadside interviews performed at 15 places on highways, trunk roads and other main roads in 9 road regions in Finland during winter 1992-93. The interviews also involved measurement of driving speeds and examinations of tyre wear. The drivers of a total of 3 350 cars and vans were interviewed and the types of their vehicles examined.

Road slipperiness was divided into four categories on the basis of friction measurement: good grip (friction  $\mu > 0.45$ ), fairly good grip ( $0.35 < \mu < 0.45$ ), fairly slippery ( $0.25 < \mu < 0.35$ ) and slippery ( $\mu < 0.25$ ), and the drivers were asked to evaluate slipperiness on the same scale. The general finding was that they were poor at evaluating the actual road conditions in winter, as indicated by the fact that less than 30% of the evaluations coincided with the measured values and more than 27% differed from the latter by 2-3 categories. Women were approx. 50% less likely than men to consider the road conditions significantly better than they were, the risk being approx. 1.4 higher among drivers who had new winter tyres and almost 2-fold among persons aged 55 + years relative to younger drivers. In addition, the figure was almost 2.5 times higher under slippery but less snowy or totally snowless road conditions relative to more snowy conditions.

The drivers' evaluations of slipperiness deviated from the actual conditions more markedly the more slippery the conditions were, as indicated by the fact that under slippery conditions more than half of them (56%) regarded the grip as good or fairly good and only 14% deemed the road to be slippery. The drivers were in fact markedly more inclined to consider road conditions better than they actually were (based on friction measurements) than more slippery.

The drivers' evaluations of road slipperiness and the condition of their winter tyres did not influence their driving speeds, so that those regarding their tyres as poor or the conditions as slippery did not drive any more slowly than the others, nor did the type of winter tyre have any appreciable effect on driving speeds. In addition, no differences in terms of driving speed were observed between vehicles with studded and studless winter tyres (the latter including friction tyres, studless winter tyres or originally studded tyres) under either good or slippery road conditions.

As the ability of drivers to evaluate actual road conditions was found to be poor and as they possessed inadequate information on the condition of their winter tyres, the slipperiness of the road as such was similarly not found to have any appreciable effect on driving speed. The 80 km/h winter speed limit was considered largely a 'guideline', and a safe speed for driving even under slippery conditions. In fact there were some stretches of road on which even higher speeds were used when the road was slippery than under favourable driving conditions. Another alarming finding from the traffic safety point of view was that the drivers were not sufficiently capable of recognising the difference between fairly slippery and slippery conditions. Theoretical calculations performed with respect to areas covered by winter speed limits indicated that the distance required for bringing a vehicle to a complete halt would have been as much as 26% longer on the average slippery conditions than under fairly slippery ones.

### 3.3 Reduced use of salt

Kallberg Veli-Pekka: Teiden suolauksen vähentäminen Kuopion tiepiirissä; vaikutukset talvella 1992-1993. (**Reduced de-icing on rural roads in Finland - Effects in winter 1992-1993**). Helsinki 1993. Finnra 86/1993. ISBN 051-47-8768-4. ISSN 0788-3722. TIEL 3200210.

Look at the final report below.

Teiden suolauksen vähentämiskokeilu Savo-Karjalan tiepiirissä- Loppuraportti. (**Reduced de-icing on rural roads in Finland - Final report**). Helsinki 1995. Finnra 34/1995, ISBN 951-726-080-6, ISSN 0788-3722. TIEL3200311.

**Keywords:** winter maintenance, de-icing, salting, accidents

In an experiment in winters 1992-1993 and 1993-1994 salting of rural main roads was radically reduced in the road region of Savo-Karjala. The total length of the experimental roads was about 375 km. The total salt use per season was reduced from 6-7 tonnes/road-km to 1-1.8 tonnes/road-km. In the neighbouring road region 10-13 tonnes of salt per road-km was used each season. The figures include salt that was used mixed with sand. On the experimental roads the use of salt mixed with sand increased from 0.2-0.3 to 0.6-0.7 tonnes/road-km.

To reduce slippery road conditions sand was used instead of salt. 55-70 tonnes of sand were spread per road-km each season. On the control roads in the neighbouring road region sand use was only 7-12 tonnes/road-km.

The cost of winter maintenance in the road region was increased by about 5%. On the experimental roads the average cost increase was about 20%. The total cost of snow ploughing, road surface levelling, salting and sanding increased on roads with low traffic volumes (2 000-3 000 vehicles/day) by about 10%, the increase was about 50% on roads with higher traffic volumes (5 000-6 000 vehicles/day).

The experimental roads were more often slippery than control roads. The friction coefficient of the road surface was below the normal target level of 0.3 or too small proportion of the road width was free of ice and snow 32-41% of time on the experimental roads and 16% of time on the control roads.

The number of injury accidents on the experimental roads was 27 in the first winter and 25 in the second winter, which was about the same as the average during the five-year period before the experiment (26.8). Because the trend on control roads was decreasing the calculated effect of reduced salting was an approximate 5% increase in the number of injury accidents. On roads with traffic volumes below 6 000 vehicles/day, that contained more than 80% of all experimental roads, the increase was about 20%. This equals to four injury accidents each winter. The number of fatal accidents, however, did not increase.



During the experiment the salt concentrations in the needles of roadside pine trees reduced significantly. There were also signs that chloride concentrations in ground water were decreasing, but the amount of observations was too small for more accurate conclusions.

About three quarters of the population of the area were pleased with the reduced salting. During the experiment the positive attitudes even increased slightly.

In the experiment the salting of roads was reduced to the very minimum. The results are not applicable to other kinds of experiments in different road environment or weather conditions. It seems clear, however, that it is not reasonable to abandon salting entirely on Finnish main roads.



## 4 ENVIRONMENTAL EFFECTS

### THE ENVIRONMENTAL EFFECTS IN A NUTSHELL

#### GROUND WATER

- The salt pollution of the ground water is a problem in southern Finland, where the most heavily trafficked roads are built on an esker. Roads built on top and following an esker are adverse.
- In general, salt pollution is slower in larger aquifers. When the esker material is coarse the groundwater flow velocity increases => water circulation increases => salt pollution is slower.
- Dense layers situated unfavourably can direct the salt pollution of groundwater. At moraine areas the process of salt pollution is different.
- Wells situated close to a road salt rapidly as the size and flow velocity are small.
- At the coastal areas excessive intake of water can result in salty seawater pushing into the place of fresh water. Salt concentration in the old sea water reserves of the coastal areas can be high.
- According to the modelling studies, the salt amount of 5 t/km/a which corresponds well to the current usage does not usually raise the salt concentration in the aquifers. In some cases the salt concentration is even a bit decreased.

#### THE DISADVANTAGES OF SALTING

- Salt can be tasted when the chloride level is 200-300 mg/l.
- Water is still drinkable at the level of 400-500 mg/l.
- At the level of 250 mg/l and daily drinking of 2 litres of water, 0,5 g of salt is taken in the body. Finnish people use salt about 10 g/day => The salt level of drinking water can be a health risk only to people with high blood pressure disease.
- Chloride accelerates corrosion. => At first the problem is corrosion of pipe lines => The objective of the Medical Administration is 100 mg/l. The investigation level laid out by cities and communities and the EC objective is 25 mg/l. The WHO specification is 250 mg/l.
- Salt deposits at the bottom of aquifers has been dreaded. This has not been confirmed in the modelling studies. The sinking of salty water would seem possible only with extreme salt concentrations or very small flow velocities. Continued salting with great amounts of salt (10-20 t/km/a) will eventually lead to excessive increase of the salt concentration at small aquifers.
- The environmental risks of salting can be controlled by protection of the most risky areas and keeping the salt amount as small as technically possible.



**VEGETATION**

- The study indicated that even modest use of road salt in the road region of Savo-Karjala resulted in accumulation of salt in the pine needles. However, the salt concentrations were not high enough to cause any visible injuries. According to the study the reduced use of road salt has proved to be good for the roadside vegetation.

**DUST**

- Dust can cause breathing symptoms to people with allergies. The quartz dust from the road and sanding materials can be hazardous to health but the amounts of quartz dust remain so small that they can not form a risk factor according to the current knowledge.
- Dusting and formation of wet, dirty fog can be controlled by traditional maintenance i.e. by opening up slush drains, moving snowbanks, well-timed peeling of ice from the embankments and by auxiliary measures (draining melt water, washing and brushing) as the need arises. Constructional changes in the roads can also be used to decrease dusting and/or assist in the maintenance needed to decrease dust and dusting.

**ALTERNATIVES TO ROAD SALT**

- Calciummagnesiumacetate (CMA) is in general similar to Sodiumchloride (NaCl) in anti-icing: Both can be applied using the same equipment and in similar circumstances. The dosage of CMA has to be about 1,3 times the weight of NaCl. As the volume weight of CMA is about 63 % from that of NaCl, one load on CMA is sufficient for about half the road length of NaCl. The effect of CMA decreases significantly at temperatures below  $-5^{\circ}\text{C}$ . The effect of CMA begins slower than NaCl and it is not effective enough for packed snow or ice.
- In Finland the oxygen content in aquifers is quite low. That's why CMA is not so suitable for us. CMA causes much less corrosion than NaCl.

**4.1 Ground water**

de Coster Amelia, Granlund Kirsti & Soveri Jouko: Tiesuolan pohjavesivaikutusten mallintaminen Joutsenonkankaalla. (**Modelling effects of road salt on groundwater in the Joutsenonkangas aquifer**). Helsinki 1993. Finnra 33/1993, ISBN 951-47-7661-5, ISSN 0788-3722, TIEL 3200158.

**Keywords:** road salt, groundwater, groundwater model

The effects of road salting on groundwater quality has been studied in an important aquifer of the terminal moraine, Salpausselkä 1. The Joutsenonkangas aquifer lies on this moraine. Highway 6 completed in 1965, traverses its entire length. The use of road salting (sodium chloride) began the same year. Even though road salt flushed from the highway is diluted by the large amount of water in storage in the aquifer, the measured chloride concentrations have increased at some waterworks due to the increased use of road



salt over the period 1965 to the present. The highest measured concentrations at these waterworks have usually been less than 20 milligrams per litre. Some private wells and sampling tubes near the highway have shown higher concentrations. The amount of salt applied on the road averages about ten tons per kilometres per year.

The main objective of this study was to use the two dimensional MOC-groundwater model to calculate present and future chloride concentrations in the Joutsenonkangas aquifer. All information on the hydrogeology and history of road salting was collected. Only a portion of the aquifer was selected for a detailed study programme due to its large areal extent. A total of 22 monitoring wells were installed during the years 1990-1992 in co-operation with the Finnish National Road Administration. Samples were taken in groundwater tubes, springs and private wells. Based on this initial data, the groundwater head and the history of chloride concentrations and migration were calculated by the model. The parameters and initial data were tested to produce a "good fit" between the measured and calculated values (calibration of the model). Once the model was calibrated, calculations were made to predict the effects of varying the amount of road salt on groundwater quality. The amounts of salt applied in the calculations were 0, 5, 10 and 20 tons per kilometres per year, over a 50 year time period commencing in the year 1992. The results of this model showed that the chloride concentrations stay rather low at water intakes if the amount of applied salt remains at its present value (approximately 10 tons per kilometres per year). The salt concentrations were higher approaching the highway and consequently the Finnish limit of 100 milligrams per litre of chloride in drinking water may be exceeded if 20 tons of road salt is applied per kilometres per year.

The MOC-groundwater model includes several assumptions on aquifer properties. The model is not able to calculate the effects of soil stratification or variations in the fluid density (due to salt stratification) on chloride transport. The results calculated by the model give a representative areal picture of chloride transport in groundwater areas of the same type and size. Detailed hydrogeologic data is a prerequisite for a more exact study of all processes involved in salt transport. More research and modelling efforts are needed in other types of aquifers and most especially eskers, as they are one of the best and most common aquifers in Finland.

Yli-Kuivila Jukka, Kivimäki Anna-Liisa & Kinnunen Timo: Tiesuolaus ja pohjavedet; Nykytilan selvitys. (**Road Salting and Groundwaters, Present Stage in Finland**). Helsinki 1993, Finnra 49/1993, ISBN 951-47-7691-7, ISSN 0788-3722, TIEL 3200174.

**Keywords:** road salt, groundwater, maintenance

The aim of the report was to get a general idea of the effects of road salting on groundwater quality, the magnitude of problems and the need for protection measures. Crucial material has been collected and analysed by the Road Regions during the years 1991-1992. Risk Assessment for important groundwater areas has been completed in 10 Water and Environment Districts (of total 13). In this method 11 factors describing road maintenance,



hydrogeology and exploitation of the aquifers are assessed and put in the scale.

The Risk Assessment is performed on 469 groundwater areas. The number covers most groundwater recharge areas with salted road sections and it corresponds to 45% of important aquifers on districts under consideration. The Risk grade can be assessed to be remarkably high (over 80 of the maximum 120) on 85 groundwater areas. 62 of them are situated in Helsinki, Turku and Kymi Water and Environment Districts.

According to the material collected by the Road Regions, chloride concentration of the groundwater has been 25 mg/l or over in 145 aquifers of 517. It has been assessed that road salting has an effect on high chloride concentrations in 98 aquifers and is the only notable factor in 32 of them. Because the follow-up sampling is performed mostly on the intake plants, the chloride concentration is probable to be high in some parts of aquifers in greater number of groundwater recharge areas. High chloride concentrations are most widely spread in Uusimaa, Turku, Häme and Kymi Road Regions, where the use of salt is also the biggest.

Because of the road maintenance and traffic, groundwater protection measures are preliminary estimated to be especially essential in 85 groundwater recharge areas. Because of the risks of road salting, 56 groundwater recharge areas should be protected. The reduction of the use of salt could be the prime method of protection in 19 of these areas. In the remaining 37 areas melting waters should be drained away. The estimated construction costs for these 37 areas would rise to FIM 94 mill.

Kling Terhi, Niemi Auli & Pirhonen Veijo: Tiesuolan pohjavesivaikutukset- Kulkeutumismekanismien moni-ilmiömallinnus. (**Effects of road salt on groundwater - modelling of transport processes**). Helsinki 1993, Finnra 65/1993, ISBN 951-478-114-7, ISSN 0788-3722, TIEL 3200190.

**Keywords:** road salt, groundwater, transport, coupled model, geochemical model

In this study, the potential groundwater contamination due to salt from highway de-icing was studied by means of numerical modelling. The objective is to understand the magnitude of subprocesses affecting the spreading of contamination, namely advection, dispersion, density effects and ion exchange. In the simulations soil parameters are varied in the range encountered in the Finnish aquifers, but site-specific studies were not carried out. In order to get a realistic description of the various interacting phenomena, coupled models were used that take into account 1 ) coupling between transport and flow (density dependent transport) and 2) coupling between geochemical equilibria and transport (coupled geohydrochemical models).

Average linear velocities for the contaminant are determined for various examples of soil types based on parameter values documented in the literature. Other factors affecting contamination spread are evaluated through sensitivity studies by systematically varying the different formation parameters. The advection velocity is most sensitive to formation permeability as this

may vary by orders of magnitude. The effect of porosity is much smaller. Dispersion does not affect the velocity by which the concentration maximum advances, but has an effect both on concentrations observed and on the areal spread of the contaminant. Effects of hydraulic gradient, seasonal variation of road salting and salt infiltration rate are also estimated.

It has been proposed that increased salt concentrations may increase the density of water enough to cause it to sink and be deposited on the bottom of the aquifer. This possibility was studied by means of density dependent transport modelling, by simulating the salt transport in different flow scenarios. Essential parameters which were systematically varied were the hydraulic gradient and formation permeability. The risk was found to be highest with high permeabilities and small hydraulic gradients. With increasing gradients the velocities increase and sinking no longer occurs. With low permeabilities the risk is reduced due to lower vertical permeabilities but increased due to lower horizontal flow velocities. The density effects were also studied in a vertical cross-section of the Joutsenonkangas aquifer in the Salpausselkä terminal moraine.

In case of salt pollution from highways the situation is most critical when the road follows rather than runs across an esker formation. A comparison simulation was carried out to estimate quantitatively this effect in a typical formation were found to be even ten times higher than for a road crossing the esker formation.

The effect of vertical heterogeneity was studied by simulating salt transport in different vertical cross-sections. The results demonstrate the effect of permeability contrasts on the transport process. Flow velocities differ with different permeabilities. While most of the chloride is transported in the high permeability layers, these layers are also cleaned faster, and different concentrations can be observed at different depths depending on the time of observation. For example, higher concentrations in the lower parts of the aquifer are not necessarily due to sinking of the denser saline water, but they can also be due to vertical permeability contrasts.

Road salt (NaCl) has two chemically different components. Chloride is practically non-reactive, but part of the sodium may be absorbed in the soil due to ion exchange. To simulate the difference in behaviour of the two components, a coupled geohydrochemical model was used. This approach can also be used in multi-source-evaluations where several potential pollutants exist. However, to get reliable results good knowledge about the mineral composition of the soil and chemical composition of the groundwater are essential.

Niemi Auli, Kling Terhi, Vaitinen Tiina, Vahanne Pasi, Kivimäki Anna-Liisa & Hatva Tuomo: Tiesuolauksen pohjavesivaikutusten simulointi tyyppimuodostumissa. (The simulation of ground water effects of road salting in type formations). Helsinki 1994. Finnra 66/1994, ISBN 951-726-013-X, ISSN 0788-3722, TIEL 3200275.



This study was part of a research programme investigating the potential contamination of groundwaters due to salt from highway de-icing. The programme is a joint effort by the Finnish National Road Administration, the Technical Research Centre of Finland and the National Board of Waters and Environment. The results have been used, for example, in the Road Traffic in Winter- programme, launched to find socioeconomically optimal approaches to the winter maintenance of Finnish highways.

In this sub-project the spreading of salt is modelled in example groundwater formations. The formations are synthetic, but chosen to represent conditions representative of the Finnish groundwater formations vulnerable to this type of pollution. A nation wide risk-assessment study, in which several hundreds of groundwater formations were classified and analysed for their risk of pollution from highway salting, was used as a basis when determining these example formations.

In each case, first the average steady state groundwater flow field is determined in which the spreading of salt from the highway is then modelled. The history of spreading from the beginning of salt usage to the present is modelled first. The results from 1992 show the anticipated behaviour, with high concentrations near the road, decreasing towards the sides of the formation and towards the water intake plant. An exception is the formation which collects salt-rich water from its surroundings due to pumping exceeding the natural yield of the formation. The water intake plant has a diluting effect on chloride concentrations and the concentrations observed at the plants are considerably lower than those in the vicinity of the roads. The size of the formation is a significant factor affecting chloride concentrations; in the example case, the chloride concentrations at the water intake plant were about 100 mg/l in a minimum size formation, whereas in a similar medium size formation they were about 20 mg/l.

Since no real existing ground water formation was investigated, the modelling results cannot be calibrated against site-specific data. Therefore the reliability of the results is evaluated through comparison with data from 300 existing formations from which the different factors affecting the spread of the chloride were analysed statistically. The results of this statistical study can best be compared with the modelling results at water intake plants. Simulated chloride concentrations in medium size formations were usually about 20 mg/l, varying between 16-34 mg/l, the size of the formation being the most significant factor affecting the concentration. In the statistical data the concentrations were of the same order of magnitude, the average concentrations varying between 16-26 mg/l and the median (for data classified according to formation type) values between 10-23 mg/l. Taking into account the approximations involved in both the modelling and the statistical study, the agreement is good and the modelling results can therefore be considered as being of the correct order of magnitude. The models can then also be used for making order-of-magnitude predictions of future developments.

In prediction simulations for 1992 to 2022 three different scenarios are studied: 1) salting will be continued at the high level of the early nineties (9.6 t/kma), 2) no salt will be used, and 3) the amount of salt used will be reduced to about half of the high values (5.0 t/kma). If the application of salt continues at the highest level the concentrations at water intake plants in medium



size formations will increase to about 30-50 mg/l in 30 years, with much higher concentrations being observed in the vicinity of the roads. During the same period, the values at the water intake plant in a minimum size formation will increase up to 170 mg/l and will be highest near the vicinity of the road, at around 240 mg/l. If no salt is used, concentrations usually fall below 10 mg/l in 30 years. In the case studied, decreasing the amount of salt used to about half causes either an increase of a few units or, in the case of the minimum size formation, a decrease of a few units.

Based on the results of the simulations, order-of-magnitude estimates can be made about average spread and development of chloride contamination in groundwater formations of different type and size. The results are approximate and the trends observed in the results can be used as supplementary information when making site specific estimates about the current status and future development of chloride concentrations. It should be emphasised, however, that as modelling results always depend on the parameter values used, site specific estimates always require understanding of and taking into account the local geohydrological conditions.

Hänninen Tuija, Kivimäki Anna-Liisa, Liponkoski Markku & Niemi Auli: Tiesuolauksen vaikutus tärkeillä pohjavesialueilla- tilastollinen tarkastelu. (Road salting on important aquifers - statistical study). Helsinki 1994, Finnra 70/1994. TIEL 4000102.

**Keywords:** road salt, groundwater, water quality, chloride, electrical conductivity

This study was part of a project to study the effects of road salting on groundwater quality. The project, in which the Technical Research Centre of Finland was also involved, was financed by The Finnish National Road Administration and the National Board of Waters and the Environment. This report presents detailed data on groundwater quality from important aquifers. Variations in chloride concentrations and electrical conductivity under different hydrogeological conditions were examined.

In the national risk assessment project the risks of road salting have been assessed on about 600 important aquifers. Hydrogeological data on these aquifers were collected from the database maintained by the Water and Environment Districts. Detailed data on groundwater quality were collected from 309 aquifers using several sources. The total number of observation points is about 800 and the number of analysis results for both chloride concentration and electrical conductivity is about 2 600.

As a consequence of increased usage of road salt for road maintenance at the end of the 1980s, chloride concentrations have increased in several aquifers. The effect of road salting is seen more clearly in aquifers with small surface areas than in those with large groundwater recharge areas. If the road regions are considered individually, the results show that the median value of chloride concentration is still less than 25 mg/l. However, in a few observation tubes chloride concentrations from 130 mg/l up to 160 mg/l have been observed. This is higher than the maximum concentration allowed by the national potable water directives. In some areas there may be potential



salt sources other than road salting. Identification of source of groundwater salinisation requires detailed field investigations.

The chloride concentration is generally higher in synclinal than in anticlinal aquifers, because in the former contaminants are transported into the aquifer from the surrounding area, too. The median value of chloride concentration in synclinal aquifers was 23 mg/l, but in other types of aquifers it ranged from 10 mg/l to 18 mg/l. The trend and variations in electrical conductivity were generally very similar to variations in chloride concentrations.

Salt applied to roads and accumulated in the surface layers of roadside slopes percolates through roadside soils and enters aquifers with precipitation recharge in spring. Seasonal variations in the concentration of chloride can be clearly observed, that is, the highest concentrations usually occur from June to August. Salt is transported with the groundwater flow and thus the concentrations decrease through dilution. The distance between the road and observation point is the main factor affecting the level of chloride concentrations that can be measured. In contrast, it seems that the concentration of chloride at water intake is not dependent on the amount of water extraction, that is, the ratio of water extraction to water yield.

## 4.2 Vegetation

Hautala Eeva-Liisa & Kärenlampi Lauri: Tiesuolan käytön vähentämisen vaikutukset tienvarren mäntyyn. (Reduction in the use of road salt and its effects on roadside pine (*Pinus sylvestris*): salt concentrations and visible injuries in needles during years 1992-94). Finnra 49/1994. ISBN 95147-9441-9, ISSN 0788 3722, TIEL 3200258.

**Keywords:** road salt, roadside vegetation, pine

In autumn 1992, at the region of Savo-Karjala, an experiment was started, where the use of road salt was reduced to minimum. Environmental impact of such an experiment were studied broadly. The effects on the accumulation of salt concentrations visible injuries on pine needles (*Pinus sylvestris*) were investigated in a field study during two winters, i.e. 1992-93 and 1993-94. Two sampling plots along the highway 9, near the border between Savo-Karjala and Central Finland Regions, were selected. At the Savo-Karjala Region, the use of road salt was reduced to about one tenth from the previous year. Where as, the use of road salt continued normally at the Central Finland Region. First and second year needle samples from pine were collected during 1992-93 and 1993-94 winters. Third-year needles were also collected during the 1993-94 winter. Visible injuries in the needles were recorded. Sampling was done eight times during the entire period of the study. In autumn 1992 and spring 1993, soil samples for element analysis were also collected.

During the two-year study, reduction in the use of road salt, clearly reduced the accumulation of road salt components (sodium and chloride) in the needles of pines that were along the roadside. The use of calcium chloride did not have any effect on the calcium concentrations in pine needles. This was probably due to small amounts of calcium chloride used in the sampling plot

areas. Positive effects of decreased amount of road salt used were observed already during the first year of the study. Salt concentrations in the needles of Savo-Karjala region were clearly lower and the visible injuries were insignificant than those observed in Central Finland Region. In the sampling plot at Central Finland Region, where road salt was heavily used, browning and premature needle loss were detected especially during spring. In the spring time also the sodium and chloride concentrations in the needles were highest. Injuries were observed at 2.5 meter height that supports our earlier findings, where the aerial uptake of salty spray was observed to be more important for the accumulation of salt in plants than the uptake via root system.

Despite the remarkable reduction in the use of road salt, accumulation of salt in pine needles was still observed in Savo-Karjala Region. However, salt concentrations were not high enough to cause any visible injuries.

The sodium and chloride concentrations in all the needle year classes lowered during the summer compared to the high concentrations in spring at both the sampling plots. However, the concentrations of salt in needles at Central Finland Region were still higher in autumn than the background level. The salt concentrations observed in the first-year needles were high even though the needles were not yet exposed directly to the salty spray. Thus, the stress caused by the heavy usage of road salt remains remarkably longer than the use of salt itself. However, deleterious effects of road salt did not reach far from the road. At distances of 20 to 30 meters, the salt concentrations and visible injuries in needles were insignificant.

During winters, density and amount of salt used, according to the weather conditions, has a significant effect on the accumulation of salt in needles and the visible injuries. Cold winter 1993-94 promoted the appearance of visible injuries at Central Finland Region. During mild winter 1992-93 more salt was accumulated to the needles than in winter 1993-94. However, visible injuries were not severe in winter 1992-93. Thus, the salt concentrations and visible injuries caused by such concentrations of salt should always be considered with respect to the meteorological data obtained during that time.

The second year of the present study showed no significant reduction in either accumulation of salt or visible injuries in needles at Savo-Karjala Region compared to the first year of study. Thus the positive effects of reducing the use of road salt may appear following the first year of the reduction. On the basis of present study, the reduction in the use of road salt is clearly beneficial to the roadside plants.

### 4.3 Dust

Nastojen, hiekoituksen ja suolauksen aiheuttama pöly ja sen leviäminen ympäristöön: kirjallisuustutkimus. (Dust caused by studs, sanding and salting and its environmental effects) Helsinki 1992. Finnra 70/1992. ISBN 951-476850-7, ISSN 0788-3722. TIEL3200120.

Keywords: CMA, studs, dust, salting, sanding.



Dust and in wet conditions a mixture of water, dust and salt are a part of winter traffic in Finland. Dust and wet, dirty fog generated by traffic can be transported by turbulent wind and air relatively far from the road. It can chemically change during the transportation. To increase friction on roads and prevent slipperiness on streets and roads 1,35 million tons of sand and 120 000 t of salt are used annually in Finland. Calculated on the basis of the annual traffic amount and the wear of the pavement, the material loss (mainly fine, powder like material) from paved roads caused by traffic is ca. 300 000 tons pro year. Estimates on other dust sources, like the use of sand for skid prevention on streets and roads and common wear, has not been presented. The dust amount on all streets and roads is largest in spring, March and April, because of wear caused by studded tyres and sand in winter traffic. In autumn, in October and November, another period with high dust concentrations in urban air and in traffic environment can be observed, as well.

Weather conditions will affect greatly both on the concentrations and transportation of the impurities in the air (car exhausts and dust) and the chemical and physical reactions of the impurities in the road environment. Other impurities, like lead and hydrocarbons, are also adsorbed by the fine, airborne particulate matter and dust generated by the traffic. A substantial part of the data concerning health effects caused by traffic emissions are based on results obtained on laboratory animals. Very little research on health effects caused by traffic emissions has been done on human populations. This research is difficult because of shortcomings in research methodology, for example lack of dose-response data and many other interfering factors.

To control dusting and formation of wet, dirty fog in winter road conditions many traditional road keeping operations can be made removal of snow and ice, controlling and draining the melt water from roads, washing, brushing etc. Also by introducing constructional changes in roads (fast drainage, etc.) can the formation of dust and wet, dirty fog be prevented. These changes will also affect positively to the road keeping operations.

Dust concentrations in open air at different traffic conditions have been widely reported. The effect of road keeping operations on dusting and dust formation at different city and urban areas have also been reported. On the contrary, the chemical composition and - properties of the wet, dirty fog caused by studded tyres, sand, car exhausts and salt from different roads and streets has not been reported in Finland or internationally.

Tieliikenteen, kunnossapidon ja nastojen vaikutus pölyyn ilmassa. (The effects of road traffic, maintenance and studs on floating dust). Helsinki 1994. Finnra 60/1994. TIEL 4000093.

High floating dust content in air is nowadays a problem in most city centres and in the vicinity of heavily trafficked roads. Many towns have emphasised the removal of sanding materials in the spring and the degree of sanding has been diminished in order to decrease the amount of dust nuisance. The measured dust contents are still above the desired values of air quality at street level in city centres and near the desired values in residential areas. The main inconvenience caused by dust is the decrease in living comfort - the

dust crunches in the teeth and grinds in the eyes, the buildings, furniture and interiors get dirty. These nuisances can be decreased by intensified maintenance. The generation of the nuisances can be inhibited by the means of land use and traffic planning.

The purpose of this study was to generate information about the dust contents and their environmental effects in different winter maintenance strategies. As the use of salt and percentage of studded tyres decreases the need for sanding usually increases.

The inconveniences of dust arise mostly in towns and other built-up areas. There are 1 800 km of salted public roads, 15 000 km of streets and 6 000 km of local plan streets in built-up areas. The main anti-skid treatment material in built-up areas is nowadays either salted sand or plain sand. The halving of salt use from the amounts used in the beginning of the 90's would not have a marked effect on the need for sanding. In built-up areas the rain waters are usually drained by sewers making the use of salt possible. By using better quality sand, checking the sand amounts and emphasising sand removal new dust nuisances can be inhibited and the current ones decreased.

The termination of salt use on public roads in nearly all circumstances will increase the need for sanding and the dust inconveniences will increase from the present. In the situation where half of the cars would have studless winter tyres, the need for sanding would not increase markedly from the present level in towns and other built-up areas. The move to studless winter traffic would very probably increase the dust inconveniences of sand clearly.

#### 4.4 Alternatives to road salt

Ylikuivila Jukka: CMA:n suotautumisen lysimetrikokeet talvikaudella 1993-1994. (Infiltration studies of CMA by Finnra in winter 1993-1994). Helsinki 1994, Finnra 34/1994. TIEL 4000078.

**Keywords:** CMA, groundwater, maintenance

Small scale infiltration studies were carried out during the winter 1993-1994 to determine how the massive use of calcium magnesium acetate (CMA) would affect groundwaters. Three vessels (depth 1.9 m, length 1.0 m and width 2.0 m) were inserted in the ground. Two of them were filled with sandy gravel and one with coarse sand. Two smaller vessels (0.058 m<sup>2</sup>, depth 0.9 m) filled with sandy gravel were used for comparison. Circumstances in the test vessels were favourable for the infiltration of CMA: all the rain was either filtrated or evaporated because of the coarse and even surface, and the growing surface for microbes was poor because of the small content of fine or organic matter.

The complete CMA dosage was about 1 kg/m<sup>2</sup>, which would correspond to the load on the main roads in Southern Finland, if de-icing were carried out by CMA instead of sodium chloride.



BOD<sub>7</sub> and acetate concentration in infiltrated melting waters were up to 2 000 mg/l. Total residue of nondecomposable acetate corresponded to about 20 per cent of the input with a CMA dosage. The total acetate residue was slightly higher in sandy gravel than in coarse sand, but the contents stayed at a high level longer in coarse sand. Calcium concentrations rose up to 200-300 mg/l and magnesium concentrations to 150-200 mg/l.

The decomposition of acetate was more effective in a smaller vessel (95%) probably because of higher temperatures (the vessel was not placed in the ground) and a more porous structure to the filling.

Infiltration of nondecomposable acetate to deeper ground layers was so significant in these tests that massive de-icing with CMA should not take place in groundwater areas. Because low oxygen content is a common problem in typically shallow and eutrophic lakes in Finland, the use of CMA is not recommended elsewhere either.

## 5 MAINTENANCE

### MAINTENANCE IN A NUTSHELL

- In the studies of the logistic effects of winter maintenance the number and recurrence of late arrivals was considered more important than the time of lateness of a single transport.
  - Reducing the amount of salt increased the transport times by 1-5% and studless winter tyres by 2%. Using less salt increases the annual transport costs by 0.05-0.5% and using studless winter tyres by 0.1-0.3%.
  - Using less salt increases the standard deviation of the transport speed increasing also the risk of delay by 5-10% and the total risk of delay by 0.5-1%. The increased transport time would have significance only when the logistics activities have developed to the level where small delays wouldn't be covered by elasticity in the logistics chain.
- 
- Discontinuing the salting almost totally increased the costs of winter maintenance of a busy road (6 000 vehicles/day) even by 50%. The costs of winter maintenance were increased also on roads with less traffic but the effects were smaller than on the busy roads.
  - Wet, including salty, road conditions prevailed for 46-49% of the winter period at Uusimaa, the western coast region and central Finland, whereas in the Kuopio and the northern coastal area the percentage of wet conditions was 25% of the wintertime. The percentage of frost and icy road conditions in winter time was 11-13% except in northern Finland where the percentage was about 20%.
- 
- Hard packed snow (built for this purpose) wore twice as fast in the studded tyre tracks than in the control tracks as measured from the cross section areas. Softer packed snow wore at the same speed both in studded tyre and control tracks.
  - Two locked brakings of trucks on a road surface covered with packed snow collapsed the deceleration values. On the side of studless winter tyres deceleration decreased by 53% and on the side of studded tyres by 36%.
- 
- The introduction of light studs would decrease rutting to 40-50% and the forbiddance of studs to 20-30% of the current rutting level. The lower values in the range of the rutting values derives from the consideration of paving development increasing the rutting and deformation resistance of pavements.
  - The effect of alternative stud wears on maintenance costs can be studied in to ways using the pavement management system (PMS). At first the long term target level of maintenance required to maintain the current road network must be calculated. The long term target level of maintenance costs is 102 million US\$/a based on the current rutting



levels. The introduction of light studs and friction tyres would decrease the maintenance costs by 17 million US\$/a i.e. to 86 million US\$/a in the year 1998. The banning of studded tyres would decrease the costs by a further 8 million US\$/a i.e. to 78 million US\$/a. The total decrease in maintenance costs of the stud ban would thus be 22 million US\$/a based on the current situation. As the current situation will anyway change towards the light stud alternative on account of the current stud regulations, the ultimate effect of a stud ban would be only 8 million US\$/a.

- In bridge maintenance the additional annual costs caused by winter salting are about 6 million US\$ and the additional costs of corrosion damage prevention in the construction of new bridges are about 2 million US\$/a bringing the total up to 8 million US\$/a. The greatest additional cost is due to the repair of the salt and steel corrosion damages of steel reinforced concrete constructions. The annual savings in the maintenance of bridges from the ending of salting would be 6 million US\$, but the effect would be marked only after 10-15 years.

## 5.1 Winter maintenance

Kalenoja Hanna & Mäntynen Jorma: Talvikunnossapidon laadun logistiset vaikutukset. (The logistic effects of the quality of winter road maintenance). Helsinki 1993. Finnra 37/1993. TIEL 3200162.

Road conditions and properties of traffic have a strong influence on traffic safety, operating and time costs. The effects of transport network on transport time are not profoundly identified. Transport time is affected by conditions of road network and traffic, road maintenance, weather and road conditions. The most difficult task in determining the logistics effects of winter road maintenance is to separate one factor from another.

Transport infrastructure has only seldom been considered as a limiting factor in the development of the logistics system. In industry the most important targets in logistics development are usually to decrease the logistics costs and to increase the overall profitability. Improving the qualities of transport properties such as transport time, speed and costs have also been considered as one of the most important objectives in logistics development. The increase of transport speed and reliability affects on productivity and decreases the capital costs of warehousing. In practice, the transport infrastructure investments have been found to have only a minor influence on inventory level. Only a relatively small part of the risk of delay is caused by road winter conditions.

According to the transport quality inquiry executed in this study the importance of transport reliability varies in different lines of industry. The most vulnerable areas regarding transport reliability are food and building industry. Approximately one half of the enterprises estimated, that over three hours' delay will have severe impacts on production. The frequency of delays has been considered as a more important factor than the length of the delay.

In Kuopio Region an experiment with reduced use of salt has been carried out during the winter 1992/93. The average speed of heavy vehicles was somewhat lower compared to the previous winter or the Central Finland Region. Especially the amount of very low speeds has increased. In difficult road and weather conditions  $v_5$ -values, which show the speed that 5% of the traffic flow falls below, have been 6-10% lower than previous year or in Central Finland Region. The reduction in average speed or median speed was very small.

The effects of road winter maintenance on transport time were studied with four transport route case studies. The changes in transport time were calculated when the amount of salt is decreased or when the use of studded tyres decreases. The results indicate that using less salt for road de-icing increases the average transport time by 1-5%. Unstudded tyres increases the transport time by 2%. Using less salt for de-icing increases the annual transport costs by 0,05 - 0,5% and using studless winter tyres by 0,1-0,3%. Using less salt would at the national level increase transport costs annually by 2-27 million US dollars and using more studless winter tyres by 6-17 million US dollars. The effect on logistics costs would be 0,05-0,2%. In addition to the transport time, road winter maintenance has influence on the standard deviation of transport speeds. Using less salt increases the standard deviation of the transport speed, which reflects on the risk of delay. The risk of delay caused by winter conditions will increase by 5-10% and total risk of delay by 0,5-1%, when less salt is used in winter. The increased transport time would have significance only when the logistics activities have developed to the level, where small delays wouldn't be covered by elasticity in the logistics chain.

Anila Matti & Kallberg Veli-Pekka: Nastarenkaiden vaikutus polanteen kulumisnopeuteen ja tienpinnan kitkaominaisuuksiin. (The effects of studded tyres on road surface wear and friction on icy and snowy roads). Helsinki 1994. Finnsra 26/1994. TIEL 4000072.

The effects of studded and studless winter tyres on road surface wear and friction on icy and snowy surfaces were studied on a test track. Two surfaces were prepared for the experiment by spreading snow on a natural hard icy surface and packing it by lorries. Water was mixed into the snow to speed up the packing process. The two surfaces differed in respect to the amount of water used. Therefore they also had different resistance to wear. Measurements of road surface wear were also made on public roads.

The two test surfaces were worn by four test cars so that the left wheel track had 85% of the wheel passes from studded tyres and 15% from studless winter tyres (stud track). The right wheel track had 15% of the wheel passes from studded tyres and 85% from studless winter tyres (comparison track).

Surface wear in the stud track was twice as fast as in the comparison track on the harder of the two surfaces. On the softer surface the speed of wear was about the same in both tracks. It is concluded that on the harder surface studs loosened small bits of the ice and snow surface which did not happen on the softer surface.



On public roads under normal traffic conditions the fastest observed road surface wear was about the same magnitude as the slowest observed wear on the test track. In most cases the wear on the artificial surfaces of the test track was several times faster than in natural road conditions. In natural conditions the differences in the speed of surface wear between the stud track and the comparison track would probably have been even greater than the observed 100%

On the harder of the two surfaces, the roughness of the bottom of the track was about 20% greater on the stud track than on the comparison track in the end of the test. The roughness increased during the test so that in the end it was about twice as high as in the beginning, even in the comparison track. On the softer of the two surfaces, however, roughness increased only in the stud track.

Braking deceleration in the tracks was measured by tests where test cars were braked by one front wheel only. Studless winter tyres were used in all braking tests. Deceleration in the stud track was about 10% higher than in the comparison track in locked wheel braking. In braking tests with anti-lock brakes (ABS) on hard icy surfaces the deceleration in the stud track was 50-100% higher than in the comparison track. Loose snow on the surface diminished the difference between the stud and comparison tracks in tests with ABS brakes.

**Matti Anila & Kari Alppivuori: Lumipolanteen kiillottuminen. (The effects of polishing of packed snow). Helsinki 1994. Finnra 39/1994. TIEL 4000082.**

During snowfall the snow on the road was packed in two different ways using cars and lorries. Deceleration was measured at locations driven over at a constant speed and at locations where braking had taken place. One lane of the road had only studless car and lorry traffic. The traffic on the other lane consisted of cars with studded tyres and lorries with winter tyres (studless) and, at study times, the measurement car with studless winter tyres. The share of studded traffic was thus from 56 to 73%. The measurement car was equipped with a data logging device developed from a Peiseler instrument. The deceleration measurements were made using ABS brakes. The study investigated the decline of deceleration due to the polishing effect of traffic on packed snow.

On the lane with studded constant speed traffic the deceleration was 18% greater than on the lane with studless traffic due to the roughening effect of studs.

Two locked brakings of lorries ruin the levels of deceleration. Deceleration dropped by 53% from 3.41 m/s<sup>2</sup> to 1.60 m/s<sup>2</sup> on the lane with studless traffic and by 36% from 3.30 m/s<sup>2</sup> to 2.10 m/s<sup>2</sup> on the lane with studded traffic. The change is difficult to perceive by a car user if the altered place can not be predicted.

On the lane with studless traffic the polishing continues after two locked brakings by lorries though no more locked brakings are made. The deceleration level drops to a level of 1.1 m/s<sup>2</sup> which is 68% of the value at the beginning

of the measurements. Locked brakings of cars do not have a significant effect.

On the lane with studded traffic the polishing does not continue significantly after two locked brakings by lorries if brakings are made without locking. Locked brakings of cars decrease the deceleration level further. The deceleration level drops to a level of  $1.2 \text{ m/s}^2$  which is 45% of the value at the beginning of the measurements.

Rönnholm Markku, Huura Jorma & Häkkä-Rönnholm Eva: Teiden talvisuolauksen vaikutus korroosiokustannuksiin (**Influence of road de-icing salt on corrosion induced costs**). Helsinki 1994, Finnra 51/1994. ISBN 951-17-9445-1, ISSN 0788-3722, TIEL3200260.

The authors analyse the cost effect of spreading de-icing salt on roads; corrosion induced costs to cars, to maintenance of bridges and to other metal structures. The corrosion cost of cars are in the chapter 'vehicular costs'.

The use of de-icing salt causes a US\$ 6 million additional maintenance cost to bridges annually. Each year, in new construction of bridges, US\$ 2 million are invested to prevent corrosion damages. This totals US\$ 8 million per year. The repair of damages to reinforced concrete, caused by corrosion and combined freeze-thaw-salt attack, forms the biggest additional cost. In Finland, if we were to stop spreading de-icing salt on roads, the saving in bridge maintenance costs would total US\$ 6 million annually. However, the influence would be noticeable only after 10 to 15 years.

The spreading of de-icing salt hardly influences corrosion of traffic signs and lighting poles because, due to technical or traffic technical reasons, they need to be renewed before their service time is up.

To estimate the repair costs, caused by de-icing salt induced corrosion of corrugated steel sheet culverts and bridges, a shorter service life was applied to them. The calculated annual cost, US\$ 1 million, is of minor importance as well as inexact because many characteristics of the soil and the water, that vary according to the environmental conditions, have a greater influence on the corrosion of the steel sheet. Cutting the amount of salt by 90 % compared with today would yield an annual saving of US\$ 1 to 6 million.

Corrosion induced repair costs of mains were not studied because background information was not available and since the corrosion of a pipe is also affected by many other characteristics of the soil. The corrosion of pipes caused by spreading salt on roads in winter is probably limited to the immediate vicinity of the road.

## 5.2 Pavements

Asfalttipäällysteiden suunnitteluperusteiden vertailu nastallisen ja nastattoman liikenteen välillä, kirjallisuustutkimus. (**The effects of studs on pavement design**). Helsinki 1993. Finnra 17/1993. TIEL 3200144.



In Finland the wearing courses of asphalt pavements are designed primarily to resist the wear caused by studded tyres. If the use of studded tyres were finished it would change the design criteria of wearing courses in Finland. The purpose of this study is to investigate consequences in pavement design by means of researches and specifications published in Finland and countries with studless winter tyres. The main subjects were the most serviceable asphalt mixes for wearing courses and their design, performance, surface characteristics and maintenance.

The composition of asphalt mixtures in Finland is to a great extent determined on the basis of wearing resistance. For this reason the most important part in mix design is the choice of aggregate. With studless traffic the main effects causing surface failures are wheel loads of commercial vehicles, thermal stresses and effects of water. The main failures are permanent deformation, fatigue cracking, ravelling and thermal cracking at low temperatures. With studless traffic aggregate, bitumen and mix proportions play all as important role in pavement performance. The most remarkable differences in asphalt mixtures are smaller maximum grain size of mixtures and higher bitumen stiffness in countries with studless winter tyres compared with Finland.

The wearing course design includes as an essential part several surface characteristics which affect rideability, traffic safety and environment. The main surface characteristics are skidding resistance, evenness, noise reduction and light reflection. In Finland evenness and skid resistance has been included in specifications of new asphalt pavements and evenness is also used as a condition criterion in pavement rehabilitation. Skid resistance has the greatest importance in countries with studless traffic because it affects traffic safety especially on wet pavements. In many of the countries with studless winter tyres skid resistance decreases considerably because studless winter tyres polish wearing courses. Polishing occurs also in winter when road surfaces are covered by an ice layer or packed snow. In many studless countries wearing courses must occasionally rehabilitated because of low skid resistance. In Finland roughening effect of studded tyres enables sufficient skidding resistance of surfaces. In the design of asphalt mixes the friction can be influenced with the surface texture and the choice of aggregate.

In Finland the selection of asphalt mixes is rather small because only rough asphalt concrete and stone mastic asphalt (SMA) can resist the wear of studded tyres. If the use of studded tyres were finished it would enable the use of new types of asphalt mixes and wearing courses with better surface characteristic. Pavement types such as surface dressings and slurry seals could be taken on more common use. In many of the countries with studless winter tyres common asphalt mix types are also porous asphalt and hot rolled asphalt (HRA) which are considered to be included in new EC-standards. Their possible use in Finland would require further investigations. In this study it was also investigated the use of ice-retardant pavements like Verglimit- and rubber modified asphalt pavements.

In pavement maintenance the use of studless winter tyres would decrease the need of wearing course rehabilitation. This results for one thing from the decrease of rutting. Secondly the decrease of maximum grain size in asphalt mixes would reduce the ravelling of surface caused by segregation which

occurs at pavement construction. On the other hand the polishing of wearing courses would increase the need of rehabilitation. In winter maintenance the extent of de-icing of roads could not be influenced remarkably by pavement techniques. From the new pavement types Verglimit- and rubber-modified asphalt pavements would slow down the formation of slipperiness and give extra time for de-icing treatments but they do not replace or decrease considerably the use of de-icing agents. Porous asphalt require for their part more extensive use of de-icing agents and more careful timing of de-icing treatments.

Kurki Timo: Rajoitetun suolan käytön vaikutus asfalttibetonin kulumiseen. (The influences of reduced salting to pavement wear). Helsinki 1994. Finnra 46/1994. ISBN 951-47-9438-9, ISSN 0788-3722. TIEL 3200255.

Look at the final report below.

Kurki Timo: Rajoitetun suolan käytön vaikutus päällysteiden kulumiseen. (The influences of reduced salting to pavement wear). Espoo 1995. VTT Yhdyskuntatekniikka 252.

The aim of the study was to find out the influences of salting to pavements wear. Two roads with exactly the same pavement were compared. Road A (Mt 637/Keski-Suomi road region) was salted during winters and on the road B (Vt 9/Savo-Karjala road region) salt was not used .

Weather information was collected from two meteorological stations and three road meteorological stations. Despite of the fact the weather was slightly more wet in the area where salt was not used the road B was dryer.

Road inventory was made weekly. It showed, that there was not packed snow on road A and the road B was totally covered with snow 7 times (weekly inventory) during two winters. The studded tyre season lasts about 20 weeks in one winter season.

Traffic counts showed that ADT was 5200 on road A and 2950 on road B . The average velocity of passenger cars was 79 km/h on road A and 88 km/h on road B.

The wear during two winters (1993-1995) was 115 cm<sup>2</sup> and 3,8 mm on road A and 86 cm<sup>2</sup> and 2,6 mm on road B. Total rut depth is 7,9 mm on road A and 6,7 mm on road B.

When the wear results were standardised with speed and traffic volume (non-linear), it showed, that the wear is about 20 % smaller on road B where salt was not used than on road A where salt was used.



Virtala Pertti: Nastojen vähentämisen vaikutus kunnossapitokustannuksiin. (The effects of studded tyres on the maintenance costs of asphalt concrete roads), Helsinki 1994. Finnra 58/1994, ISSN 0788 3722, ISBN 951-47-945-2, TIEL 3200267.

**Keywords:** Studded tyres, maintenance costs, rutting.

The goal of these subprojects was to study different winter maintenance strategies and their influence on maintenance costs user costs etc.

One subproject was to study the effects of studded tyres on the maintenance costs of asphalt concrete roads. In this study the network level Pavement Management System (PMS) was used to estimate these effects.

Stud regulations, the use of studs and the effects which studs have on deterioration were used while estimating the effects that restricted use of studs has on rutting. The deterioration models used in the pms-system were developed from the condition data measured in years 1989-1991. Rutting is one factor in these deterioration models.

Two different models were used to estimate the effect of studded tyres. In the first scenario the percentile of tyres with lighter studs would increase to 75% and the percentile of friction tyres to 15% of all studded tyres before the year 1998. In another scenario the use of studded tyres would be forbidden from the year 1998 on. The first model would decrease the rutting of pavements 40-55% compared to the current situation. The second model would decrease the rutting even more, 70-80%. The bigger numbers represent the situation where the deterioration of pavements is slower because of the stronger pavements developed in the ASTO-project.

The effect of alternative stud wears on maintenance costs can be studied in two ways using the pavement management system (PMS). At first the long term target level of maintenance required to maintain the current road network must be calculated. The long term target level of maintenance costs is 102 million US\$/a based on the current rutting levels. The introduction of light studs and friction tyres would decrease the maintenance costs by 17 million US\$/a i.e. to 86 million US\$/a in the year 1998. The banning of studded tyres would decrease the costs by a further 8 million US\$/a i.e. to 78 million US\$/a. The total decrease in maintenance costs of the stud ban would thus be 22 million US\$/a based on the current situation. As the current situation will anyway change towards the light stud alternative on account of the current stud regulations, the ultimate effect of a stud ban would be only 8 million US\$/a.

The second alternative is to find out how the scenarios affect the long term maintenance costs. According to the results of the PMS, the optimal budget level to maintain the asphalt concrete road network is to start with 111 million US\$ in 1994 and decrease the amount annually so that the total budget is 844 million US\$ in 8 years. The light stud scenario would decrease the total maintenance costs about 67 million US\$ in 8 years and forbidding the studded tyres from the year 1998 on would decrease them about 108 million US\$ in 8 years compared to the current maintenance level.

It is well known that using studded tyres has many other effects on user costs, winter maintenance costs etc. The conclusion is that the effect studded tyres have on maintenance costs is not very significant and the benefit of forbidding the use of studded tyres is not very remarkable.



## 6 VEHICULAR COSTS

### VEHICULAR COSTS IN A NUTSHELL

- The fuel consumption of a car on a slippery, snowy and uneven road increases by 15% compared to the consumption on a dry, bare and even road. The changes in consumption depending on road geometry are greater than those depending on road conditions.
- The fuel consumption with studded tyres is 1.2% greater than with studless winter tyres. The difference does not depend totally on the studs as the tyres compared were of a different type.
- The annual corrosion costs were calculated as 156 US\$ per car. With the current passenger car base the total corrosion costs are about 289 million US\$/a, half of it is caused by salting. The amount of salt used has a distinct effect on the corrosion costs and regional variations are great. In the calculations of total social costs the corrosion costs of cars were instead based on the prevention costs and the costs were about a half of the former.

Anila Matti & Kallberg Veli-Pekka: Talvikelin vaikutus henkilöauton poltto-  
nesteiden kulutukseen. (The effects of icy and snowy road surface condi-  
tions on fuel consumption). Helsinki 1994. Finnra 27/1994. TIEL 4000073.

**Keywords:** fuel consumption, road surface, studded tyres, winter tyres.

The effects of icy and snowy road surface conditions on fuel consumption were studied by field measurements with an instrumented car in winter 1993-1994. Measurements were made in different road categories and in locations of varying winter maintenance practices, both with studded and studless winter tyres. A decrease in the friction coefficient by 0,1 (e.g. from 0,4 to 0,3) increased fuel consumption by 0,7%. The difference in fuel consumption between bear pavement and most slippery icy road surface was about 4%. 1 cm of loose snow in the wheel tracks increased fuel consumption by about 4% and 2 cm of snow by about 7%. There were no observations of deeper snow depths. When unevenness of the road surface increased so that it affected driving comfort fuel consumption increased by about 3%.

According to the results fuel consumption on slippery, snowy and uneven roads can be about 15% higher than on bare, dry and even surface. Variations in fuel consumption due to road geometry, however are even greater. The largest differences in fuel consumption between the five road locations where the measurements were made were about 20%.

Fuel consumption with studded tyres was 1,2% higher than with studless winter tyres. The difference, however, is not necessarily entirely due to studs because also tyres were different. Measurements were made using only one set of studded tyres and one set of studless winter tyres.

Rönnholm Markku, Huura Jorma & Häkkä-Rönnholm Eva: Teiden talvisuolauksen vaikutus korroosiokustannuksiin ( **Influence of road de-icing salt on corrosion induced costs**). Helsinki 1994, Finnra 51/1994. ISBN 951-17-9445-1, ISSN 0788-3722, TIEL3200260.

**Keywords:** de-icing salt, corrosion induced costs, cars, bridges, metal structures

The authors analyse the cost effect of spreading de-icing salt on roads; corrosion induced costs to cars, to maintenance of bridges and to other metal structures.

To map the costs of the use of de-icing salt, car importers were asked to give an estimate of the required, corrosion induced extra measures and costs of car maintenance and repair. In addition to the body, brakes, electrical equipment, suspension of wheels, exhaust pipe and cooler were checked for corrosion. The results were compiled applying 18 years of use as the basis for comparison, and then the annual costs were calculated. An average corrosion induced cost of US\$ 156 per car annually, and adds to US\$ 289 million for the total car stock of today, and half of it is caused by salting. The amount of salt used considerably influences the costs induced by corrosion. The extent of corrosion varies by the region.



## 7 ROAD USER EXPERIENCES

### ROAD USER EXPERIENCES IN A NUTSHELL

- The greatest disadvantage of studded tyre use in Japan was perceived to be the particle dust separated by the studs. As traffic increased in the 1980's and also the number of vehicles with studded tyres increased, stud dust and its environmental influences became a great social problem in all "wintery" and densely trafficked cities.
- Thus far the experiences from the winter traffic in Japan show no "alarming" signs after the move to studless winter tyres. Accidents with studless winter tyres have somewhat increased in built-up areas in very slippery road conditions, when even careful driving cannot ensure safety. It is, however, possible that even safety savings have occurred during normal winter conditions as the benefits of more careful driving are more apparent.
- In spite of rains, slipperiness and packed snow the drivers of heavy traffic in Finland estimated the road conditions rather as at least fair than bad. It seems that the driver of heavy vehicles are more "accustomed" to driving on slippery and bad road conditions.
- 63% of the bus drivers and 83% of the lorry drivers did not think that reduced salting impeded staying on schedule. Only 1% thought that reduced salting had hindered them quite often.
- The small amount of road salt experiment in the Province of Kuopio was welcomed positively. The experiment increased the number of people opposed to the use of salt. The use of road salt was most often opposed to due to the environmental inconveniences. As expected, the representatives of the heavy traffic to a more positive attitude towards the use of road salt than the drivers of private cars. They motivated this with the increased traffic safety. The road users did not feel that the decrease in the use of road salt caused any great inconvenience. On the contrary, the attitudes of driver responsibility and driving comfort were usually increased.
- The acceptance of the future scenarios specified in the Road Traffic in Winter -project was tested using the weighting from a conjoint study. Normal road users saw that the primary alternative was very limited salt use combined with the current studded tyres and the current level of winter speed limits. As the use of salt would be decreased from the present, the environmental influences and car depreciation would be on a lower level. The top management of the Finnish National Road Administration preferred 50 % salting, the current policy of tyres and changing speed limits. Traffic safety and environmental issues would be emphasised, but the salt content of ground water could increase within the recommended levels and car depreciation could continue at the current level. Environmental and traffic safety experts saw reduced salting and current studded tyres as the primary alternative. They also hoped for lower winter speed limits and increased traffic safety.

Niemelä Pauli & Kainulainen Sakari: Tiestön kunnossapito vähemmällä suolauksella. (**The maintenance of roads using reduced salt**). Helsinki 1994. Finnra 38/1994. ISSN 0788-3722, ISBN 951-479430-3. TIEL 3200247.

**Keywords:** traffic, attitudes, safety, road salting

With this research is produced information about the attitudes of the population in the province of Kuopio towards the experiment which was carried out as reduction in use of road salt. As survey areas were the attitudes connected with the traffic safety and the driving situation, the question of the use of road salt as a road maintenance and an environmental question as well as the question of the road network as a general question.

The survey was performed as a three-phase inquiry for the population in the Provinces of Kuopio and Centre Finland. The first inquiry was sent to 1 000 persons in both of the provinces. At the first stage (autumn 1992) the attitudes of the population were clarified before the above mentioned experiment, at the second stage (spring 1993) the attitudes of the population were measured with the same measurements and of the same persons - after the experiment, and at the third stage (spring 1994) the permanence of the changes was clarified. On this report the results of the first, second and third phase have been presented. The results of the first winter and the further examination of the starting situation, has been stated in the intermediate report of the research called "Reduction in use of road salt" (Reports of the Finnish Road Administration 67/1993).

In the inquiry of the autumn 1992 that was a basic information of the research, was cleared up the fact that traffic safety was considered to be a matter of utmost importance. According to the opinions of the persons giving the replies the conditions of the winter must however not be changed in to those existing in the summertime, in the winter it may be slippery and the first thing to be influenced when improving the traffic safety is the attitudes of the drivers (driving habits) although the use of road salt, as a general way of changing the conditions, was resisted it also was hoped to be used as a way of warding off the most dangerous and unexpected slippery that will say the first slippery in the autumn and the rush hours.

The first and the second winter of small amount of road salt was positively welcomed in the Province of Kuopio. The share of the population in the Province of Kuopio against the road salt had increased during the experimental winter. In the Province of Centre Finland (the region of comparison) the situation had almost remained unchanged. In the Province of Kuopio was also less commonly appealed to the fact that the traffic safety is increased by the influence of the use of road salt than in the starting situation and in the Province of comparison. The use of road salt was most often opposed against due to the environmental disadvantage it caused. The representatives of the heavy traffic took a more positive attitude - this could perhaps be expected - towards the use of road salt than the drives of the private cars. They still appealed to the fact that the increasing traffic safety is a consequence of the use of road salt. According to the results the drivers didn't felt that the reduction of the use of road salt caused them any harm. On the contrary the



attitudes of a driver concerning the responsibility and the driving convenience as a general have increased.

Niemelä Pauli, Laurinkari Juhani, Kainulainen Sakari & Tuunanen Risto: Suolan käytön vähentäminen, väliraportti väestön asenteista Kuopion läänin kokeiluun talvikaudella 1992-1993. (Reduction in use of road salt - intermediate report on population attitudes toward experiment in the Province of Kuopio during the winter period 1992-1993). Helsinki 1993, Finnra 67/1993. ISSN 0788-3722. ISBN 951-47-8118-X.TIEL 3200192.

**Keywords:** traffic, attitudes, safety, road salting

With the research survey "Reduction in use of road salt" information is produced on the attitudes of the population toward the experiment on the limited use of road salt to be realised in the Province of Kuopio. As survey areas are the attitudes connected with the traffic safety and the driving situation, the question of the use of road salt as a road maintenance and an environmental question as well as the condition of the road network as a general question.

The survey is performed as a three-phase population opinion poll in the Provinces of Kuopio and Centre Finland. The first questioning was sent to 1 500 persons in both of the provinces. At the first stage (autumn 1992) the attitudes of the population were clarified before the above mentioned experiment, at the second stage (spring 1993) was measured - with the same measures and of the same persons - the attitudes of the population after the experiment. The third questioning will be realised in the spring of 1994. In this report the results of the first and second phase are examined in a general way.

As a basic information of the survey in the questioning of the autumn 1992 was found out that the traffic safety is considered to be a matter of utmost importance. According to the opinions of the persons giving the replies the conditions of the winter must, however, not be changed in to those existing in the summertime: in the winter it may be slippery and the primary measure in improving the traffic safety was the influencing on the attitudes of the drivers behaviour. Although the use of road salt was as a factor changing the conditions opposed against, but its use was again hoped for directed on the prevention of the worst and most surprisingly slippery spots on the road. These dangers were the first slippery roads of the autumn and the rush hours.

The first winter of small amount of road salt (92/93) was positively welcomed in the Province of Kuopio. The experimental winter had increased among the population of the Province of Kuopio the share of people opposing against the use of road salt. In the Province of Centre Finland, or in the control region, the situation had remained almost unchanged. In the Province of Kuopio was also referred to the increasing effect of the use of road salt on the traffic safety more scarcely than in the previous autumn or among the comparison votes. The use of road salt was most often opposed against due to the environmental inconveniences it caused. The representatives of the heavy traffic took a more positive attitude - this could perhaps be expected toward the



use of road salt than the drives of the private cars. They motivated this still with the increased traffic safety as a consequence of the use of road salt.

Leppänen, Anne & Byckling, Timo: Talviliikenteen järjestelyjen painopisteet. (Preferences regarding Winter Traffic Arrangements). Helsinki 1994. Finnra 70/1994. ISSN 0788-3722, ISBN 951-726-021-0. TIEL 3200279.

**Keywords:** winter traffic, preferences, conjoint analysis

Conjoint analysis is a method of studying consumer preferences among multiattribute product or service alternatives. The technique was used to measure the preferences regarding winter traffic arrangements among a general driver sample and three different groups of experts. Conjoint analysis gives more accurate and realistic picture of the interest groups' preferences than standard attitude scales, since it does not allow the respondent to choose only good things but forces him to make trade-offs between different alternatives.

The data is derived from a general population sample of about one hundred private car drivers from each of the following provinces: Kuopio, Kymi and Uusimaa, and from three expert groups, the top management of the Finnish National Road Administration, traffic safety and environmental specialists. Adaptive Conjoint Analysis (ACA) was chosen to implement both the data-gathering phase and the statistical estimation procedure. Seven attributes with 3-4 attribute levels each were specified: use of road salt, winter speed limits, choice of winter tyres, ground water salt content, corrosion and level of environmental protection and traffic safety. Utilities for the attribute levels were estimated by OLS, and average weights were calculated to reflect relative preferences. The main findings on each attribute are summarised below.

As far as road salt is concerned, the preferences of the Finnish National Road Administration top management are close to those of the general driver sample, although they tend to adopt a more cautious attitude towards giving up road salting. The environmental experts preferred more than any other group a reduced usage of road salt.

The most popular alternative of winter speed levels appeared to be a variable speed limit sign, depending on weather conditions, although the present winter time limit of 80 km/h got a high utility score as well. The most preferred choice of winter tyres by all the groups was currently widely used studded tyres. Experts put more emphasis on improved studded tyres and a usage tax, whereas the general driver sample were more inclined than experts to accept friction tyres.

Preserving the ground water areas in their natural state was clearly the most preferred alternative by all the groups except for the representatives of the Finnish National Road Administration. The decline in vehicle values due to corrosion was not considered an important attribute. Experts accepted the present value loss caused by corrosion, while to ordinary drivers preserving the value of their cars against corrosion was more important.



The present level of environmental protection was sufficient for the representatives of the Finnish National Road Administration and the driver sample, whereas the traffic safety and environmental experts wanted an enhanced or greatly enhanced level of environmental protection. On top of the list, all the groups put an increased or greatly increased level of traffic safety. The highest utility value was recorded for the traffic safety group, followed by the environmental group.

A number of future scenarios have been defined in The Road Traffic in Winter Project. The acceptability of the scenarios was examined by the ACA simulation facility using the utility values discussed above.

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